

in this issue

ELECTRIFICATION OF THUNDERSTORMS

HIGH-GAIN PANEL LIGHT AMPLIFIER

CROSSED-FIELD TRAVELING-WAVE DEVICES

MULTI-PORT BICONICAL ANTENNA

PROPAGATION ABOVE 40 MC

DEPLETION LAYER TRANSISTORS

NUMERICAL TRANSFORM CALCULUS

IRE COMMITTEES AND REPRESENTATIVES

TRANSACTIONS ABSTRACTS

ABSTRACTS AND REFERENCES

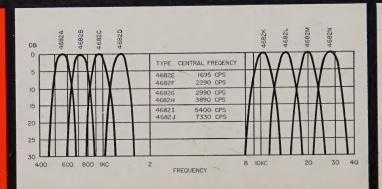


## FOR EVERY APPLICATION



#### TELEMETERING FILTERS

UTC manufactures a wide variety of band pass filters for multi-channel telemetering. Illustrated are a group of filters supplied for 400 cycle to 40 KC service. Miniaturized units have been made for many applications. For example a group of 4 cubic inch units which provide 50 channels between 4 KC and 100 KC.









Dimensions: (3834) 1½ x 1¾ x 2-3/16". (2000, 1) 1¼ x 1¾ x 15%".

# NLTS VOLTS 2 2000 3834 12 4 2000 150 200 150 200 250 FREQUENCY

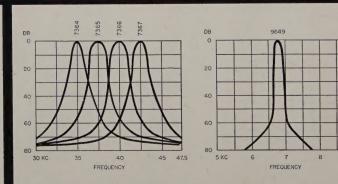
#### AIRCRAFT FILTERS

UTC has produced the bulk of filters used in aircraft equipment for over a decade. The curve at the left is that of a miniaturized (1020 cycles) range filter providing high attenuation between voice and range frequencies.

Curves at the right are that of our miniaturized 90 and 150 cycle filters for glide path systems.

#### CARRIER FILTERS

A wide variety of carrier filters are available for specific applications. This type of tone channel filter can be supplied in a varied range of band widths and attenuations. The curves shown are typical units.

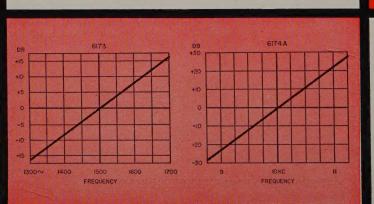




Dimensions: (7364 series) 15% x 15% x 25/4". (9649) 11/2 x 2 x 4".

#### DISCRIMINATORS

These high Q discriminators provide exceptional amplification and linearity. Typical characteristics available are illustrated by the low and higher frequency curves shown.





#### UNITED TRANSFORMER CORPORATION

150 Varick Street, New York 13, N.Y.

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## SOLID-ELECTROLYTE TANTALEX® CAPACITORS

new dimensions in

miniaturization and reliability

This solid-electrolyte Tantalex Capacitor (shown  $1\frac{1}{2}$  times actual size) is rated at 4.7  $\mu$ F, 10 volts d-c, and is only  $\frac{1}{8}$  in diameter by  $\frac{1}{4}$  long.

Now, circuit designers in computers and military electronics have an electrolytic capacitor that offers greater miniaturization than ever before . . . with no sacrifice in reliability. Sprague's recently announced solid-electrolyte Tantalex Capacitors find ideal application in the transistor circuits of these critical fields.

The tiny sintered tantalum anode of Type 150D Tantalex Capacitor is impregnated with a solid, non-corrosive, semi-conductor material which cannot leak under any circumstance. It combines true miniaturization with electrical stability previously unobtainable in an electrolytic capacitor of any type.

Thermal coefficient of these capacitors is sufficiently low and linear so that for the first time a circuit designer can think of an electrolytic in terms of parts per million capacitance change. Nominal value is  $+500 \text{ ppm}/^{\circ}\text{C}$ . The

capacitor may be used without derating over a range from +85°C to as low as -80°C, a temperature at which no other electrolytic has proved useful.

Solid construction permits the Type 150D to withstand the severe shock and vibration encountered in missile and ballistic applications. Hermetic sealing makes it completely immune to humid atmospheric conditions.

Complete performance data covering the wide range of sizes and ratings are in Engineering Bulletin 3520A, available on letterhead request to the Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Mass.

\* \* \*

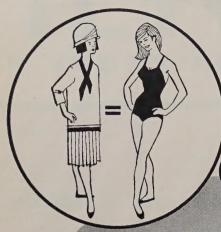
Sprague, on request, will provide you with complete application engineering service in the use of Tantalex Capacitors.

SPRAGUE®
the trademark of reliability

SPRAGUE COMPONENTS:

CAPACITORS • RESISTORS • MAGNETIC COMPONENTS • TRANSISTORS • INTERFERENCE FILTERS • HIGH TEMPERATURE MAGNET WIRE • PULSE NETWORKS • PRINTED CIRCUITS

### **CONVERSION PROBLEM?**



ERA's

TRANSISTORIZED

### NVERTERS

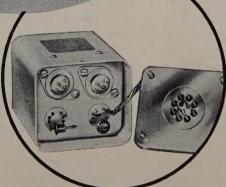
CONVERTERS

TRANSPAC® semi-conductor converters/inverters pioneered by ERA converts low voltage DC into higher voltage DC, or AC. These converters eliminate the drawbacks inherent in mechanical vibrators and rotary equipment and are ideally suited for powering all types of battery operated equipment, aircraft and missile circuitry, radio relay and communication systems, and all portable and mobile apparatus.

TRANSPAC converters incorporate balanced transistor circuitry\* which provides for maximum conversion efficiency with negligible interaction on the DC feed supply. Self-starting, diode stabilized designs. Uses special "E" core magnetic circuits for optimum thermal stability and freedom from spurious modes. Fully protected against external short circuits and overloads. Units are potted and sealed in MIL-T-27 transformer type housings but transistors are readily accessible for servicing and replacement purposes.

® Trade Mark Registered

- Semi-Conductor Designs, Non-Mechanical
- Small Size, Light Weight
- Zero Operating Maintenance
- Maximum Conversion
- Rugged: High Shock, **Vibration Resistant**
- Instant Starting
- **Negligible Radio Interference**
- Overload and Short Circuit Protected



STANDARD MODELS available in stock non-regulated types for all battery voltages. Stock converters provide DC outputs 150-350 VDC up to 200 MA. Stock inverters supply AC outputs 60 or 400 cps up to 50VA. SPECIAL MODELS available in regulated and high power types with ratings in excess of one KW. Designs also supplied to meet special customer requirements. Write for quotation on standard or special models.

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As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

October 16-18, 1957

IRE Canadian Convention, Exhibition Park, Toronto, Ont., Canada.

Exhibits: Mr. E. O. Swan, 512 Bayview Ave., Toronto 17, Ont., Canada.

October 18-19, 1957

Digital Computer Symposium, O'Henry Hotel, Greensboro, N.C.

Exhibits: Mr. M. L. Fox, Western Electric Co., Burlington, N.C.

October 28-30, 1957

East Coast Aeronautical and Navigational Conference, Lord Baltimore Hotel & Seventh Region Armory, Baltimore, Md.

Exhibits: Mr. C. R. Maynard, Westing-house Electric Corp., Box 746, Baltimore, Md.

November 6-7, 1957

Third Annual Symposium on Aeronautical Communications, Hotel Utica, Utica, N.Y.

Exhibits: Mr. Chan P. Thomas, 52 Oxford Rd., New Hartford, N.Y.

November 11-13, 1957

Third Instrument Conference & Exhibit, Biltmore Hotel, Atlanta, Ga.

Exhibits: Mr. W. B. Wrigley, Eng. Exp. Sta., Georgia Tech., Atlanta 13, Ga.

November 13-14, 1957

IRE Mid-America Electronics Conference, Municipal Auditorium, Kansas City, Mo.

Exhibits: Mr. Ted V. Anderson, Central Technical Institute, 1644 Wyandotte St., Kansas City, Mo.

November 15-16, 1957

New England Radio-Electronics Meeting, Mechanics Hall, Boston, Mass.

Exhibits: Mr. Howard H. Dawes, General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

November 18-20, 1957

Conference on Magnetism & Magnetic Material, Hotel Sheraton Park.

Washington, D.C.

Exhibits: Mr. David S. Bender, 930 H St.,
N.W., Washington 1, D.C.

December 4-5, 1957

Professional Group on Vehicular Communications Annual Meeting, Statler Hotel, Washington, D.C. Exhibits: Mr. Robert C. Abel, American Trucking Association, 1424 16th St., N.W., Washington 6, D.C.

December 9-13, 1957

Eastern Joint Computer Conference, Park Sheraton Hotel, Washington,

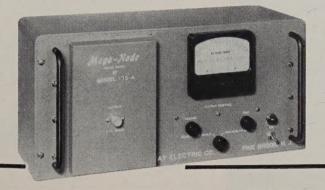
Exhibits: Dr. S. N. Alexander, National Bureau of Standards, Washington 25,

(Continued on page 8A)

### **KAY ELECTRIC Noise Figure Measure Equipment Now Augmented with Improved Versions of NEW LONDON Random Noise Sources**

The New London Random Noise Sources added to the Kay Electric line have been refined and improved by Kay engineers. The most important change is the increased stability obtained from a regulated power supply.

Kay Electric Company now offers the most complete and versatile line of Random Noise Sources. These units feature non-tunable outputs matched over their respective frequency





#### RANDOM NOISE SOURCE for VHF-UHF

Model 175-A (formerly New London Model 175)

- Balanced Output-No Balun
- Broadband-No Tuning, 50 to 900 mc
- Long Life Diodes

This noise source, consisting of two 5722 noise diodes operating in an inherently balanced arrangement, makes full use of the distributed parameters of each diode to achieve a wide band noise output characteristic. Thus, this instrument gives noise figure readings of balanced 300 ohm receivers over the entire 50 to 900 mc frequency range without tuning.

#### **SPECIFICATIONS**

Frequency Range: Noise Figure:

50 mc to 900 mc 0 to 19 db

Accuracy: Output Impedance:

 $\pm 0.5$  db below 400 mc;  $\pm 1$  db maximum at 900 mc when using 300 ohm equipment Designed for 300 ohm balanced inputs

Tube Life:

200 hours of continuous operation at maximum output

PRICE:

\$325.00

#### RANDOM NOISE SOURCE

Model #403-A (formerly New London Model 403)

This noise source instrument measures noise figure, bandwidth, and gain of receivers, and calibrates signal sources . . . all with very high accuracy. It features a VSWR of less than 1.3 over the entire frequency range of 3 to 500 mc. Long-life, inexpensive noise diodes are used, and no tuning is required.

#### **SPECIFICATIONS**

Frequency Range:

Noise Figure: Accuracy:

0 to 19 db direct reading

Output Impedance:

±0.5 db over entire frequency range 50 ohms unbalanced

PRICE:

3 mc to 500 mc

#### - ALSO AVAILABLE -

#### **UHF NOISE SOURCE MODEL #191-A**

(formerly New London Model 191)

Frequency Range: 10-3,000 mc

PRICE: \$790.00

ALL PRICES F.O.B. FACTORY

#### PLUS THE REGULAR LINE OF KAY ELECTRIC -NOISE SOURCES AND NOISE FIGURE MEASURING SETS

Mega-Node (Cat. No. 240-A)-Frequency Range: 5 to 220 mc. Noise Figure Range: 0 to 16 db at nom. 50 ohms; 0 to 23.8 db at 300 ohms. Output Impedance: Unbalanced-50, 75, 150, 300 ohms, Infinity; Balanced-

Mega-Node Sr. (Cat. No. 250-B)-Frequency Range: 10 to 3,000 mc. Noise Figure Range: 0 to 20 db. Output Impedance: Nom. 50 ohms into type N connector. Price

100, 150, 300, 600 ohms, Infinity. Price: \$295.00

Rada-Node (Cat. No. 600-A)-Frequency Range: 5 to 26,500 mc.

Noise Figure Range: 0 to 23.8 db depending on output impedance; accurate to ±0.25 db. Price: \$1,395.00 (For frequencies to 400 mc. Other standard noise sources may be used with Rada-Node at prices shown.)

Microwave Mega-Nodes-Frequency Ranges: 1,200 to 26,500 mc. Noise Output: Fluorescent-15.8 db ± 0.25 db; Argon-15.28 db ± 0.1 db. Prices: \$295.00 to \$595.00 with power supply

For Literature on Complete Line of Kay Instruments, Write:

#### KAY ELECTRIC COMPANY

Dept. I-10

14 Maple Avenue, Pine Brook, N.J.

CAldwell 6-4000

### look what \$2450 buys in test equipment!



#### HEATHKITS GIVE YOU TWICE AS MUCH equipment for every dollar invested

The famous model V-7A Vacuum-Tube-Voltmeter is a perfect example of the high-quality Instruments available from Heath at 1/2 the price you would expect to pay! Complete, \$2450



Get the most out of your test equipment budget by utilizing HEATHKIT instruments in your laboratory or on your production line. Get high quality equipment, without paying the usual premium price, by dealing directly with the manufacturer, and by letting engineers or technicians assemble Heathkits between rush periods. Comprehensive instructions insure minimum construction time. You'll get more equipment for the same investment, and be able to fill your needs by choosing from the more than 100 different electronic kits by Heath. These are the most popular "do-it-yourself" kits in the world, so why not investigate their possibilities in your particular area of activity! Write for the free Heathkit catalog now!



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Also describes Heathkit ham gear and hi-fi equipment in kit form. 100 interesting and profitable "do-it-yourself" projects!

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(Continued from page 6A)

March 24-27, 1958

Radio Engineering Show and IRE National Convention, New York Coliseum and Waldorf-Astoria Hotel,

New York, N.Y.

Exhibits: Mr. William C. Copp, Institute of Radio Engineers, 72 W. 45th St., New York 36, N.Y.

South Western IRE Conference & Electronics Show, Municipal Auditorium and San Antonio Hotel, San

Antonio, Texas.

Exhibits: Mr. Bill Case, P.O. Box 55,

San Antonio 6, Texas.

April 30-May 2, 1958

Seventh Region Technical Conference & Trade Show, Hobbies Bldg., State Fair Grounds, Sacramento, Calif. Exhibits: Mr. Ewald W. Berger, 3421 58th St., Sacramento 20, Calif.

May 12-14, 1958

National Aeronautical & Navigational Electronics Conference, Day-ton Biltmore Hotel, Dayton, Ohio. Exhibits: Mr. Donald V. Meyers, 6962 Miami Rd., Cincinnati 27, Ohio.

June 4-6, 1958

Armed Forces Communications & **Electronics Association Convention** & Exhibit, Sheraton-Park Hotel, Washington, D.C. Exhibits: Mr. William C. Copp, 72 West 45th St., New York 36, N.Y.

Second National Symposium on Production Techniques, New York,

Exhibits: Mr. Warren D. Novak, General Precision Laboratories, Pleasantville, N.Y.

August 19-22, 1958

Western Electronic Show and Convention, Ambassador Hotel and Pan Pacific Auditorium, Los Angeles,

Exhibits: Mr. Don Larson, WESCON, 342 North LaBrea Ave., Los Angeles 36, Calif.

October 13-15, 1958

National Electronics Conference, Sherman Hotel, Chicago, Ill.

Exhibits: Mr. J. S. Powers, National Electronics Conference, 84 East Randolph St., Chicago, Ill.

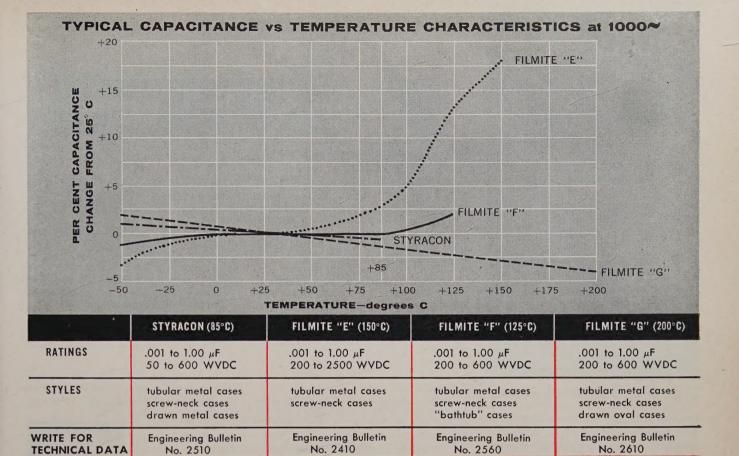
October 27-29, 1958

Radio Fall Meeting, Sheraton Hotel,

Rochester, N.Y.

Exhibits: Mr. Virgil Graham, RETMA, 11 West 42nd St., New York 36, N.Y.

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information.
Advertising Department and of course listings are free to IRE Professional Groups.



#### 4 kinds of film dielectric capacitors

for specialized applications

Here are four plastic-film dielectric capacitors now in regular production at Sprague:

STYRACON CAPACITORS find wide application in laboratory equipment and in industrial controls where their low dielectric hysteresis (low "soak"), high insulation resistance, high "Q", low and linear temperature coefficient of capacitance are of great value.

FILMITE "E" CAPACITORS are general-purpose capacitors for use up to 150°C where capacitance stability with temperature is of secondary importance. They are also used at lower temperatures where very high insulation resistance is a prime requirement.

FILMITE "F" CAPACITORS are intended for use in circuits where

the absolute minimum in capacitance change with temperature is a must and relatively large capacitance values are used. These capacitors typically will be within .05% of their 25°C value from -10°C to +85°C. They may be used up to 125°C where greater capacitance excursion is tolerable.

FILMITE "G" CAPACITORS have the highest temperature rating of any organic dielectric. They may be used up to 200°C! All units are nickel-plated to withstand high temperature corrosion. They also have the highest insulation resistance, the lowest dielectric hysteresis, and the lowest dissipation factor of any capacitor made so that they are often used at lower temperatures which are above the 85°C limit of the lowercost Styracon Capacitors.

CAPACITANCE VS. TEMPERATURE CHARACTERISTICS of all four types of film capacitors are compared in the chart above for the benefit of the circuit designer.

ALL SPRAGUE FILM CAPACITORS are designed to have positive electrical contact between leads and electrodes, even at low operating voltages.

WRITE FOR ENGINEERING BUL-LETINS on the Sprague plastic-film capacitors in which you're interested. Address your letter to Sprague Electric Co., Technical Literature Section, 235 Marshall Street, North Adams, Mass.



#### SPRAGUE COMPONENTS:

CAPACITORS . RESISTORS . MAGNETIC COMPONENTS . TRANSISTORS . INTERFERENCE FILTERS . PULSE NETWORKS . HIGH TEMPERATURE MAGNET WIRE . PRINTED CIRCUITS



#### 20 uua or 0.2 uv per division sensitivity

Solve your bridge balance and low-level DC measurement problems with this sensitive, rugged, and versatile combination DC null detector, micro-microammeter, microvoltmeter, and microvolt level DC amplifer.

Current sensitivity of the Model 204A is 20 times greater than high quality, mechanical current galvanometers. As a voltage galvanometer, its extremely high power sensitivity makes it superior to moving coil instruments.

Ideal for production testing, low level DC amplification to extend the range of recording instruments, or as a direct reading indicator for strain gage, thermocouple and other current or voltage measurements in industry or laboratory.

#### SPECIFICATIONS

- 10uv to 10 volts or 0.001 ua to 1 milliamp full scale in 7 ranges
- All transistorized Rugged Insensitive to shock, microphonics, mounting position
- Withstands extreme overloads with no zero
- Floating input 10,000 ohm fixed input resistance - No restrictions on source resistance.
- 10-14 full scale power sensitivity
- Use as stable DC amplifier with 1 volt at 1 milliamp output
- Less than 2 uv drift, less than 1 uv P-P noise

Representatives Nationwide. Ask for demonstration today or write for detailed literature.



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The Navy has announced that D. G. Mazur (A'42-SM'53) has been appointed Manager, Vanguard Operations Group, at Patrick Air Force Base, Florida. In this capacity, he will supervise the Navy's part of the operations at Patrick for the earth satellite program.

Mr. Mazur, an electronic engineer, has been with the Naval Research Laboratory since 1946. Since that time, he has specialized in the design and operation of telemetering of rockets. For the past year, Mr. Mazur has served as Head of the Electronic Instrumentation Branch of Project Vanguard. Prior to that he was with NRL's Radio I Division which later became a part of the Atmosphere and

Astrophysics Division.

Before joining NRL, Mr. Mazur was employed for a short time with Colonial Radio Corporation and Curtiss Wright Corporation, both of Buffalo, New York. He also gained experience with the Naval Aircraft Factory, Philadelphia, where he was employed from December, 1940, to March, 1944, testing and inspecting radios and components and later aircraft radar. In March, 1944, he went to the Naval Air Experimental Station in Philadelphia. Pennsylvania, where he supervised evaluation testing and developing of radio and radar equipment.

A native of Buffalo, New York, he won a matriculation scholarship by competitive examination to Worcester Polytechnic Institute, from where he received the degree of Bachelor of Science in electrical engi-

neering in 1938.

Mr. Mazur is an associate member of the American Institute of Electrical Engineers, and co-holder of two patents and coapplicant of a third.

J. P. Molnar (S'54-A'55) Director of Military Development of Bell Telephone Labs., has been elected a Vice-President of

the company. In his new post Mr. Molnar will head one of Bell Laboratories' two vice presidential areas devoted to military programs.

Mr. Molnar was graduated from Oberlin College in 1937 with the A.B. degree, and received the Ph.D.



J. P. MOLNAR

degree from Massachusetts Institute of Technology in 1940. Prior to joining Bell Laboratories in 1945, he was employed with the National Defense Research Committee and with the Gulf Research and Development Company.

Since joining Bell Laboratories he has been concerned with research in physical electronics and later with the development of microwave tubes. In 1955 he was appointed Director of Electron Tube Development and later in that year was named Director of Military Systems Development. He was appointed Director of Military Development in Feb. 1957.

Mr. Molnar is a member of the American Physical Society and the Optical Society of America.

R. R. Hough (S'40-A'43-SM'46) has been named Assistant Chief Engineer of the American Telephone and Telegraph Company.

Mr. Hough was graduated from Princeton University in 1939 with a B.S.E. degree, returned to the Prince-Engineering School as an instructor and graduate student, and received an E. E. degree in 1940.



R. R. Hough

He immediately joined Bell Labs., and in 1941 became one of a group pioneering in the development of radar. He participated in the design and installation of the first U.S. naval gunfire control radar and made important contributions to the development of an army aircraft gunlaying radar. In recognition of his wartime contributions, he received a War Department Certificate of Appreciation in 1946.

After the war Mr. Hough continued to be associated with Bell Labs. development programs for the armed forces. He was named Military Development Engineer in 1951, Director of Military Systems Development in 1953, and Director of Military Electronics Development in 1955. He was elected a Vice-President in Feb. 1957.

Mr. Hough is president of the Morris County Engineers' Club, and a member of the American Institute of Electrical Engineers, Phi Beta Kappa and Sigma Xi. In 1947 he was the recipient of the Eta Kappa Nu annual award as the "outstanding young electrical engineer.'

He is a member of the Advisory Council to the Department of Electrical Engineering of Princeton University, an honorary member of the Princeton Graduate Council, and a member of the executive committee of the Princeton Engineering Association.

(Continued on page 18A)

14A

**Designed for Computers** 

Made for Computers

Tested for Computers

Dependable in Computers





### HEON RELIABLE

### COMPUTER TRANSISTORS

#### in the JETEC 30 package



Reliability must be designed and built into computer transistors. It cannot be obtained by selection.

Raytheon Computer—Transistors were developed under Signal Corps contract and are manufactured especially for computer service, on a separate production line. They are backed by five years of experience in the mass production and quality control of Raytheon Fusion-Alloy Transistors.

Maximum stability is guaranteed by rigid test procedures including strict process control, 100°C baking of every transistor, 100% steam cycling to assure positive hermetic sealing.

When you specify Raytheon Computer Transistors you are also assured of:

HIGH VOLTAGE RATINGS • HIGH CURRENT GAIN FAST SWITCHING SPEED

LOW SATURATION RESISTANCE

#### Here are the electrical specifications for Raytheon PNP Computer Transistors

-			2	2N425		2N426			2N427			2N428		
Parameter	Conditions (25°C)	Units	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
BVPT		volts	-30	-50	-	-25	-45	-	-20	-30	-	-15	-25	-
V <sub>BE</sub> 1	$I_{\text{B}} = -1 \text{mA} \ V_{\text{CE}} = -0.25 \text{v}$	volts	-	-0.35	-0.45	-	-0.35	-0.45	-	-0.35	-0.45	-	-0.35	-0.45
hee,	$I_{B} = -1 \text{ mA}$ $V_{CE} = -0.25 \text{ v}$		20	30	40	30	40	60	40	55	80	60	80	-
hee2	$I_B = -10 \text{mA}$ $V_{CE} = -0.35 \text{v}$		10	15	-	10	18	-	15	20	1	20	30	-
R <sub>sat</sub> .	$I_B = -10 \text{mA}$	ohms	for I	c = -10	3.2 0mA	for	$I_c = -10$	3.2 0mA	for	$l_{c} = -15$	2.1 0mA	for I	c = -20	1.6 0mA
fab.	$V_{CB} = -5v$ $I_E = 1 \text{ mA}$	Мс	2.5	4.0	-	3.0	6.0	-	5.0	11.0	-	10.0	17.0	-
Cob	$V_{CB} = -5v$ $I_{E} = 1 mA$	μμf	-	14	20	-	14	20	-	14	20	-	14	20
Switching Sp	eeds													-
$t_{\rm d}+t_{\rm r}$	$i_c = -50 \text{mA}$ $R_L = 200 \text{ ohms}$	μsec	-	0.53	1.0	_	0.53	1.0	-	0.43	0.85	-	0.43	0.85
ts	Values of is "on" and is "off" are	μsec	-	0.3	0.6	-	0.3	0.6	-	0.3	0.6	_	0.3	0.6
tf	5.0mA for 2N425 3.3mA for 2N426 2.5mA for 2N427 1.6mA for 2N428	μsec	_	0.45	0.65	1	0.35	0.55	-	0.35	0.55	-	0.30	0.50

For all types  $I_{c~(max.)}=-400 \text{mAdc}$  average  $I_{c~(max.)}=-1000$  mA peak

Dissipation coefficient in free air  $=0.4^{\circ}\text{C/mw}$ Dissipation coefficient with radiator  $=0.28^{\circ}\text{C/mw}$ Dissipation coefficient with infinite sink  $=0.18^{\circ}\text{C/mw}$ 

#### SEMICONDUCTOR DIVISION

Silicon and Germanium Diades and Transistors • Silicon Rectifiers

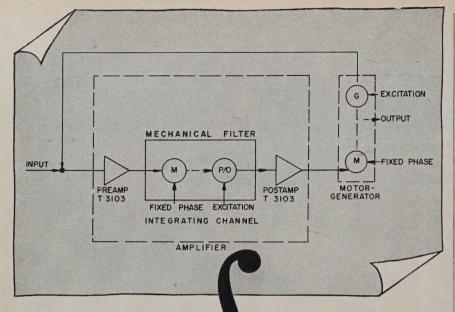
RAYTHEON

 NEW YORK:
 55 Chapel St.
 • Bigelow 4-7500

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 • PLaza 9-3900

 CHICAGO:
 9501 Grand Ave., Franklin Park
 • TUxedo 9-5400

 LOS ANGELES:
 5236 Santa Monica Blvd.
 • NOrmandy 5-4221



This diagram illustrates an optimum configuration of a precise integrating servo system.

The essential components are shown below.

## (f)dt



#### SERVO MOTOR GENERATOR

This size 15 unit represents the latest in design for precise integrating tachometers. Temperature stabilized to within 1° C; linearity, 0-3600 R.P.M., .03% of 3600 R.P.M., 0-4800 R.P.M., .05% of 3600 R.P.M.



#### MECHANICAL FILTER

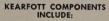
This size 11 filter, used in conjunction with amplifiers shown, provides an integral-plus-proportional circuit. Eliminates quadrature and noise in the error signal and the need for high gain, critical amplifiers.



#### TRANSISTORIZED AMPLIFIERS

This T3103 amplifier provides a 40 v., 6 w. output. Meets the requirements of MIL-E-5400. Dimensions  $1\frac{5}{8}$ " x  $1\frac{5}{8}$ " x  $1\frac{7}{8}$ " high, weight 4.7 oz.

The above units are available as components for your specific applications or as packaged sub-assemblies.



Gyros, Servo Motors, Synchros, Servo and Magnetic Amplifiers, Tachometer Generators, Hermetic Rotary Seals, Indicators and other Electrical and Mechanical Components.

#### KEARFOTT SYSTEMS INCLUDE:

Directional Gyro Compass Systems, Three Gyro Stable Platform Systems and Inertial Navigational Systems.



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#### KEARFOTT COMPANY, INC., LITTLE FALLS, N. J.

Sales and Engineering Offices: 1378 Main Avenue, Clifton, N. J.

Midwest Office: 23 W. Calendar Ave., La Grange, Ill. South Central Office: 6211 Denton Drive, Dallas, Texas

West Coast Office: 253 N. Vinedo Avenue, Pasadena, Calif.



(Continued from page 14A)

S. C. Spielman (S'33-A'35-SM'45) was recently appointed Director of Engineering for Philco's Government and Industrial

Division. Mr. Spielman will have full responsibility for all design and development engineering activities of the division.

Mr. Spielman has been Director of Electronic Engineering for the G & I Division since 1951. In this capacity he was responsible for



S. C. SPIELMAN

supervising all electronic development and design engineering.

He joined Philco as a factory engineer in 1933 after graduating from Drexel Institute of Technology. He was chief engineer in charge of television receiver design before coming to the G & I Division.

Mr. Spielman holds several patents in the field of electronics and is active in industry affairs. From 1954-55 he was IRE Philadelphia Section Chairman.

He has served on various committees of the Radio Electronics Television Manufacturers' Association and also is a member of the Institute of Navigation, American Society of Naval Engineers, American Rocket Society and American Ordnance Association.

\*\*

R. A. La Plante (A'52–M'56) has been appointed Head of the Microwave Tube Development Section of Philips Laboratories, a division of North American Philips Company, Inc., Irvington-on-Hudson, New York.

After receiving his B.S. degree in electrical engineering from Rensselaer Polytechnic Institute in 1951, Mr. La Plante joined Philips and was assigned to the Microwave Tube Research Section under George Espersen where he was engaged on a multiplicity of tube research and development programs. As a result of reorganization in February of this year, Mr. La Plante was transferred to the newlyestablished Microwave Tube Development Section.

While all microwave tube research programs will continue to be under the supervision of Mr. Espersen, the supervision of all microwave tube development projects will be Mr. La Plante's responsibility.

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The appointment of **P. S. Coomes** (S'49–A'51–M'55) as district commercial engineer for the General Electric Receiving Tube Department was announced recently.

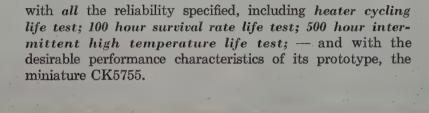
Mr. Coomes had been product planning engineer at the department headquarters in Owensboro, Kentucky, for the past two years. As a district commercial engineer he will be responsible for liaison with engi-

(Continued on page 22)

#### **Approved and Accepted in TOUGH Applications**



### CK6832 RELIABLE SUBMINIATURE TWIN TRIODE for D.C. AMPLIFIER and COMPUTER SERVICE





CK6832

26 1050 µmhos Gm

ĪЬ

0.8 mAdc

Developed for Bell Telephone Laboratories under Army Ordnance Contract.

#### Featuring:

UNIQUE ELECTRICAL STABILITY...12 mVdc, max.

The grid to grid unbalance voltage resulting from a reduction of heater voltage from 6.3 to 5.9 volts

UNIQUE MECHANICAL STABILITY...20 mVac, max.

The grid to grid unbalance voltage resulting from six repeated shocks having an acceleration of several hundred G

CLOSE BALANCE BETWEEN SECTIONS......24 mVdc, max.

> The grid to grid unbalance voltage resulting from six operating cycles of fifteen minutes "on" and five minutes "off"

LOW GRID CURRENT..................3 x 10-8A, max.

Each section

LOW MICROPHONICS......10 mVac, max.

Output of each section resulting from vibration at 40 cps, 15 G

RAYTHEON

#### **SPECIAL TUBE DIVISION**

RELIABLE MINIATURE AND SUBMINIATURE TUBES - VOLTAGE REFERENCE TUBES VOLTAGE REGULATOR TUBES PROPERTY FAILURES NUCLEONIE TUBES **NEWTON, MASS.:** 55 Chapel St. Bigelow 4-7500 NEW YORK: 589 Fifth Ave. Pl aza 9-3900 CHICAGO: 9501 Grand Ave., Franklin Park • TUxedo 9-5400 LOS ANGELES: 5236 Santa Monica Blvd. . NOrmandy 5-4221



designing their own supports, many of which

have been produced by Lapp. To standardize the great variety of tube support designs, Lapp set out to design a complete line which is now available and offers the equipment manufacturer a valuable service by way of more economical production, interchangeability and availability of replacement units. Lapp Tube Supports are compact, efficient and attractive in appearance. Their duty is threefold ... they support the tubes, insulate, and furnish an air duct which channels air over tube fins for maximum cooling. Write for Bulletin 301, with complete description and specification data. Lapp Insulator Co., Inc., Radio Specialties Division, 205 Sumner Street, LeRoy, New York.





(Continued from page 18A)

neering staffs of mid-west and southwest manufacturers of electronic equipment using receiving-type tubes. His office will be at 3800 N. Milwaukee Ave., Chicago.

After receiving a degree in electrical engineering from the University of Detroit in 1951, Mr. Coomes joined General Electric as production engineer at the company's receiving tube plant in Owensboro. Subsequently he served in marketing as an application engineer and more recently in product planning.



W. E. Lowery (A'35-M'45), a radar specialist with more than 28 years of electronics experience, has been named man-

ager of the newlyorganized reliability section at Ray-theon Manufactur-Company's ing Wayland Labora-

A 23-year veteran with the firm. Mr. Lowery graduated from Massachusetts Institute of Technology in 1929. Before



W. E. LOWERY

joining Raytheon in 1934, he worked for the Bell Telephone Laboratories and the Samson Electric Company.

During World War II he contributed to the design of the SO series of radars used extensively by Navy surface ships. More recently he was for several years in charge of all radar indicator work.

He is a member of the IRE Professional Group on Reliability and Quality Control. He is also a member of the Reliability Committee of the Radio-Electronics-Television Manufacturers' Association.



The appointment of A. F. Boscia (S'50-A'51) as chief product engineer for Kin Tel Division of Cohu Electronics, Inc., has been announced recently.

Mr. Boscia formerly was associated with Stromberg-Carlson Division of General Dynamics as section head of communications and navigation at the Rochester, New York plant. In this post he had project su-

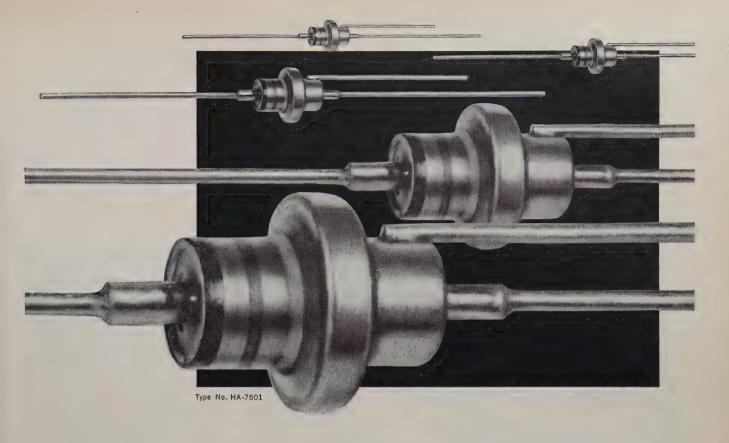


A. F. Boscia

pervision of the program for production of airborne units for TACAN, the tactical air navigation system built for the armed

At Kin Tel in San Diego, Mr. Boscia will supervise all engineering phases of production design on the Kin Tel line of instruments for communication, measure-

(Continued on page 26A)



#### here today!

#### SILICON TRANSISTORS by HUGHES

#### now in production quantities



Hughes offers a "high temperature" transistor, an alloy-junction PNP device for audio, switching, and control circuitry at medium power levels—and at junction temperatures as high as 150°C. Outstanding characteristics: power dissipation in

#### THE HUGHES PACKAGE

Here Hughes departs from the conventional to offer a transistor with coaxial leads. In contrast to the single-ended configuration, this unique design permits the maximum flow of heat from the crystal through the package while providing an extremely sturdy internal structure. Also, it permits rigid mounting (particularly on printed circuit boards), thereby increasing the ability of the equipment to withstand

free air at 25°C, 500mW...saturation resistance at 100mA collector current, 10 ohms...voltage for the common emitter connection, 50V maximum...and, in addition, high current capabilities coupled with low reverse saturation currents.

physical shock or vibration. Abetted by small size and a hermetic seal, this kind of ruggedness results in a package which is just about as practical as a package can be. Maximum dimensions: body length, .396 inch; body diameter, .343 inch.

Perhaps you saw our new transistor at the WESCON show and discussed it there. If not, and you wish additional information now, please write:

#### SEMICONDUCTOR DIVISION HUGHES PRODUCTS

International Airport Station Los Angeles 45, California

Creating a new world with ELECTRONICS

**HUGHES PRODUCTS** 



© 1957; Hughes Aircraft Company





(Continued from page 22A)

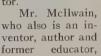
ment and control. These include wide-band dc amplifiers, microvoltmeters, industrial and broadcast television and other electronic instruments.

Mr. Boscia is a graduate of Cooper Union, in the class of 1950.



Knox McIlwain (A'31-M'40-SM'43-F'48) an electronics engineer and ballistic missiles expert, has been appointed man-

ager of the Special Products Division of the Burroughs Corporation's research center at Paoli, Pa., it was announced today by R. V. D. Campbell, deputy director.





KNOX McIlwain

will be responsible for the division's commercial and defense contracts, the latter including research and development of weapons system and airborne computers for the U. S. military services. He joined the Research Center last year as assistant to the Director and coordinator of the Center's ballistic missiles program.

He is a graduate of Princeton University where he received a Bachelor of Science degree, and the University of Pennsylvania where he earned advanced degrees in electrical engineering. He held a professorship at the Moore School of Electrical Engineering of the University of Pennsylvania, from 1924 to 1941. Prior to his teaching he was associated with the Bell Telephone Co., of Pa. Immediately prior to joining Burroughs he was chief consulting engineer for the Hazeltine Electronics Corp.

McIlwain is past vice-president of the Institute of Navigation. He has been awarded fifty patents, including an air navigation anti-collision system and a passport identification system. He has had numerous papers published, and included among his books are Electrical Engineers Handbook, High Frequency Alternating Currents, and Principles of Color Television.

He is a member of Phi Beta Kappa, Sigma Psi, Eta Kappa Nu and Tau Beta Pi.

٠

The promotion of two executives of General Precision Laboratory Inc. was announced recently.

R. L. Garman (A'39–SM'51), formerly executive vice-president of GPL, was elected to the new post of chairman of the board, and continues as technical director in charge of research and development.

J. W. Murray (S'51-A'53-M'56), formerly executive vice-president, was elected president and chief executive officer, continuing as general manager.

(Continued on page 30A)

## UNCES THE



## COMPUTER

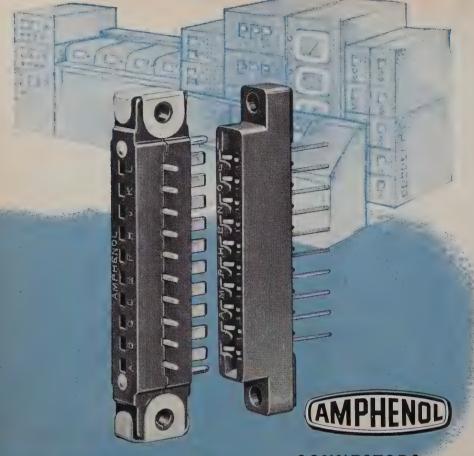
- Cathode Ray Tube Display
- Decimal or Octal Arithmetic
- High-Speed Printed Numerical Output
- No Special Air Conditioning Needed
- Low Cost

minimum of instruction, the compact new IBM 610 Auto-Point Computer provides large-scale electronic computer facilities at desk-side.

For the engineer and scientist, with a

TIME EQUIPMENT
DATA PROCESSING
ELECTRIC TYPEWRITERS
MILITARY PRODUCTS





#### PRIN-CIR CONNECTORS

Connecting printed circuits with AMPHENOL Prin-Cir components assures both ease of operation and high performance reliability. Available as plugs and receptacles, Prin-Cirs feature rugged, smooth-working gold-plated contacts and tough diallyl phthalate bodies. Application versatility is provided through a wide choice of contact terminals: Standard, Pin, Wire Wrap and Open End in receptacles; arrangements allowing for straight or angled board attachment, modular design, and cable plug-in for plugs. Plugs and receptacles available in 10, 15, 18 and 22 contacts; 6 contact receptacle also available.

Average voltage breakdown between contacts at sea level is 5400 V. DC for receptacles and 2300 V. DC for plugs.

AMPHENOL ELECTRONICS CORPORATION chicago 50, illinois AMPHENOL CANADA LTD. toronto 9, ontario



AMPHENOL Industrial Distributors carry stocks of standard AMPHENOL components in order to provide immediate service on your rush requirements





(Continued from page 26A)

L. J. Kroko (A'55) has been appointed Supervising Engineer in the Solid State Electronics Development Section of the Materials Engineering Department at Westinghouse Electric Corporation in East Pittsburgh, Pa.



#### GOVERNMENT

An FCC official told RETMA that a Commission order pertaining to a trial run of subscription TV would be delayed until sometime this fall, "certainly well beyond the Commission's August recess," the source said. The prediction was based on what was termed "inadequate" original filings (July 8) and reply briefs (July 22) by both proponents and opponents of toll-TV as to what would constitute a fair trial for pay-TV-one of the announced purposes of the proposed rule making proceeding. Though House committee chairmen Oren Harris (D., Ark.) and Emanuel Celler (D., N.Y.) have spoken out against any FCC authorization of pay-TV on a trial basis without first getting the consent of Congress, RETMA was told that the "decision on subscription TV would be reached by the FCC sometime this fall and that such a decision will be based on the Commission's belief that it has the legal authority to do so without the formal approval of Congress."... All parties were invited by the FCC to submit comments and engineering data by Oct. 1 to the feasibility of operating low-powered apparatus for repeating or retransmitting TV programs into remote, sparsely settled areas. Manufacturers were asked to submit data as to the probable cost of suitable equipment, the cost of which is known to be relatively low. The new devices would be known as "low-power TV broadcast repeater stations" and would be permitted to operate on both vhf and uhf. Translators are now authorized only on the upper 14 uhf channels. They may pick up either vhf or uhf signals but can only rebroadcast them on channels 70-83, the FCC said. The proposed rules would limit the power input to the final radio frequency amplifier to 1 watt, would establish certain minimum performance standards considered to be necessary to prevent interference to established services, and would require the inclusion of certain automatic devices to prevent malfunctioning if the

\* The data on which these Notes are based were selected by permission from *Industry Reports*, issues of July 22 and 29, and August 5, 12 and 19, published by the Radio-Electronics-Television Manufacturers Association, whose helpfulness is gratefully acknowledged.



470 Mc

DATH

PHONE

MARINE

INDUSTIL

TRANS

PERTIN

INDUST'L

200

BUILDANS MURICE

apparatus were to be operated without a technically qualified radio operator in constant attendance. TV repeater stations would be required to protect other classes of stations from interference but would receive no protection from interference. They would be permitted to operate as simple cochannel linear amplifiers, i.e., "booster," or could convert to any other vhf or uhf channel which could be used without causing interference to other classes of stations. . . . The Office of Technical Services, Commerce Department, released the following reports of electronics research: "Bonding Materials, Metallic Mating Surfaces: Low RF Impedance," PB 111930, priced at \$1.75 each; "The Field Effect and Surface Conductance On Germanium," PB 121339, priced at 75 cents each; "Diffraction and Shielding Effects of Radar Screens" PB 121918, at 50 cents each. Order from OTS, Commerce Department, Washington 25, D. C.... The Atomic Energy Commission revealed development of a dime-sized atomic battery with a useful life of more than five years and an output of 20 microwatts, versions of which, the AEC said, might be used to power portable radios and other electronic equipments.

#### MARKETING

Factory sales of transistors in June totaled 2,245,000 units with a dollar value of \$6,121,000 compared with 2,055,000 transistors sold in May valued at \$5,636,000 and 1,130,756 valued at \$3,645,293 sold in June, 1956. Cumulative sales of these devices during the first half of this year totaled 11,199,300 units valued at \$31,249,000 compared with the 4,758,000 units worth \$13,727,000 sold during the corresponding period of 1956.... Radio receiver production in June totaled 1,088,343, including 416,058 automobile receivers, compared with 1,023,771 radios made in May, which included 396,151 auto sets, and 1,073,775 radios including 296,256 auto sets made in June, 1956. Cumulative radio output during the first six months of this year totaled 7,187,294 including 2,834,676 auto sets compared with 6,659,165 receivers made during the corresponding six months of last year, including 2,313,651 auto receivers. . . . Television output in June totaled 543,778 compared with 342,386 TVs made in May and 553,025 produced in June, 1956. The number of TVs produced with uhf tuners totaled 72,766 in June against the 41,596 made in May and 78,512 in June, 1956. Cumulative TV output during the first six months of this year amounted to 2,722,139 receivers compared with 3,415,202 made during the like 1956 period.

(Continued on page 36A)

Use your IRE DIRECTORY! It's valuable!

### FM 470-10 Mc

### MARCONI SIGNAL GENERATOR

### STILL

### Unique



Exceptional stability, wide frequency range and the precisely calibrated carrier shift control make Model 1066/1 a joy to use.

First produced in 1955, it is now the accepted test instrument for narrow or wide band applications. It is still the only FM generator with such complete range.

Recent improvements have made microphony and attenuator reaction negligible and have increased tube life. The oscillator chassis is now gold plated.

#### SPECIFICATION

Frequency Range 10-470 Mc in 5 ranges. Contactless turret is capacity coupled. Frequency Stability .0025% per 10 minutes

Carrier Shift Controls Calibrated 1-200 kc continuously variable. Also stepped increments  $\pm 5$ ,  $\pm 10$ ,  $\pm 15$  kc.

Frequency Modulation 0-20 and 0-100 kc continuously variable.

Amplitude Modulation 0-80%. Output .01 $\mu$ V to 100mV, 52  $\Omega$  . Piston attenuator.

Tubes 6AK5, 6C4, 12AT7, DET22, 6L6, 5651, XB1, OB2, 5Z4G

FM Deviation Monitor Model 791C is a companion instrument. Range 4-540 Mc. Accuracy ±3%.

### SUPPLIED

TO:-

Applied Science Corp. Avco Mfg. Corp. Bell Telephone Labs. Bendix Radio **Brooklyn Polytech** Chrysler Corp. Cubic Corp. Convair Colo. State Patrol Delaware R'ric'sting Douglas Aircraft Dumont Labs. Florida Road Dept. General Electric General Mills **General Motors** Glenn L. Martin Georgia Tech. McDonnell Aircraft M.I.T. Motorola ountain States T&T **New Mexico Police** Pve Corp. Packard Bell R.C.A. Radio Marine Corp. Radioplane Co. Seguoia Process Corp.

Stromberg-Carlson Virginia University Watson Comm'ns.

Western Electric

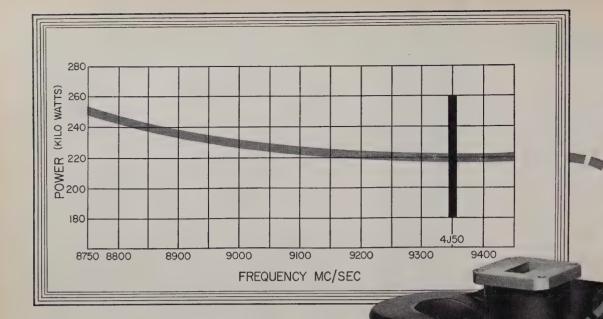
**GOV'T. AGENCIES** 

AFC Kelley A F B Navy Electronic Lab. New York Ordnance U. S. Forest Service U. S. Signal Corps White Sands P. G. Wright Patterson A F B



10 Mc

RCONI instruments STREET . NEW YORK 4, N. Y.



Sylvania duplicates the power and package of the 4J50 in a...

### 

Type 6874

Adds flexibility to existing equipment as well as to new designs

Sylvania sets the pace in magnetrons with its newest, high-powered tunable unit, type 6874, that covers the frequency range between 8800 and 9400 Mc. The tunable 6874 directly replaces the fixed frequency 4J50 magnetron. It provides rapid and inexpensive conversion of fixed frequency systems to meet latest military requirements.

Designed for airborne radar and missile applications, the 6874 is mechanically ruggedized for severe shock and vibration requirements. Thus a very compact tunable package is provided even for very severe environmental conditions.

#### Typical Characteristics:

Heater Voltage (Preh	ea	t)					13.75 Volts
Heater Current						٠	. 3.00—3.75 Amps
Peak Anode Current							27.5 Amps
Peak Power Output							
Peak Anode Voltage							21 KV
Pulse Duration		٠	٠	. 1	1.0	u	sec (3.34 sec max)
Duster Carolo							001

#### Sylvania moves ahead

in Magnetrons

With tripled magnetron production facilities now in operation at its Williamsport, Pa., plant, Sylvania meets expanding military and commercial needs. Call your Sylvania representative for full information on the complete Sylvania magnetron line.



Sylvania's Williamsport, Pa., plant houses expanded magnetron production facilities

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SYLVANIA ELECTRIC PRODUCTS INC. 1740 Broadway, New York 19, N. Y. In Canada: Sylvania Electric (Canada) Ltd. Shell Tower Bldg., Montreal

LIGHTING

**RADIO** 

TELEVISION

ELECTRONICS

### but everywherefriendly -hp- engineer

( ) Factory-level service and repairs available.

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Fort Myers, Florida Arthur Lynch & Associates 35 West North Shore Avenue EDison 2-1109

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Vancouver 2, British Columbia Atlas Radio Corporation, Ltd. 106-525 Seymour St. MUtual 3-5848

Winnipeg, Manitoba Atlas Radio Corporation, Ltd. 505 McIntyre Building

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Sweden ■ Erik Ferner AB

Switzerland Max Paul Frey Hangweg 27 Berne-Liebefeld Tel: (031) 63.36.45

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United Kingdom Livingston Laboratories Retcar Street London, N. 19, England Tel: Archway 6251 Yuaoslavia Belram Electronics 43 Ch. de Charleroi Brussels, Belgium Tel: 38.12.40

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Formosa Far-Eastern Company No. 6 Nanyang Street Taipei, Taiwan Telephone: 27876 India
The Scientific Instrument

Company, Ltd.
6, Tej Bahadur Sapru Rd.
Allahabad 1 240, Dr. Dadabhai Naoroji Rd. Bombay 1 11, Esplanade East Calcutta 1
B-7, Ajmeri Gate Extn.
New Delhi 1
30, Mount Road Madras 2

Japan Seki & Company, Ltd. Kanai Building No. 1 Kanda Higashi-Fukudacho, Chiyoda-ku, Tokyo Tel. Kayabacho

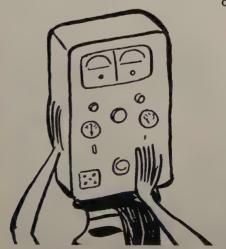
(66) 0828-3012-4712 New Zealand Geo. H. Sample & Son (N.Z.) Ltd. 431 Mount Albert Road Mount Roskill S.1, Auckland Tel: 89-439 AFRICA

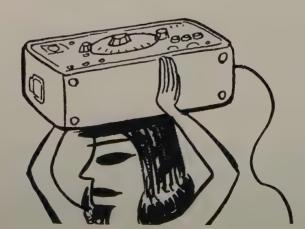
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-hp- complete coverage in electronic instruments; complete coverage in service, too!

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#### \*PRE-ASSEMBLED CIRCUITS

The ERIE Pre-Assembled Circuits system presents an entirely new approach to packaging electronic components. This new modular system is now being used by many large radio and TV manufacturers in their 1957 models. PAC has proven itself to be technically sound as well as economical and easy to handle on the assembly line.

Leading producers choose PAC—because PAC reduces labor costs...requires fewer component insertions...needs less assembly equipment... uses a smaller printed wiring board area...means fewer punched holes...reduces overhead costs...keeps inventory down.

For further information write for Engineering Bulletin 450-1 or contact your ERIE representative.





(Continued from page 31A)

#### MILITARY ELECTRONICS

The Air Force granted a \$139.3 million order to the Boeing Airplane Co. for quantity production of its IM-99 BOMARC antiaircraft missile. The contract, designed to supply the BOMARC to Air Force operating units for the first time, includes a small initial contract totaling \$7,109,195 announced in May and designed to get initial production under way at Boeing's Seattle plant, the Air Force said. . . . A new electronic altimeter, accurate within 40 feet at 60,000-foot altitudes, will replace altimeters now in use, the Air Research and Development Command announced. One dozen test models built by the Victor Division of RCA have been successfully flight tested for more than a year, the ARDC said. The new altimeter determines altitudes by sending a radar signal to the ground and measuring the time it takes to return. A total of 35 electron tubes are used in the new instrument compared to 18 in the present system but by using etched circuits, the ARDC said, the equipment's weight is held to around 35 pounds.

#### RETMA ACTIVITIES

The new name of the national electronic manufacturers organization marks the third change since the founding of the Association in Chicago in 1924 as the Radio Manufacturers Association. In 1950 "Television" was added, and in 1953 "Electronics." By an overwhelmingly favorable vote, RETMA members on July 23 voted at a proxy membership meeting to change the name of the 33year old industry organization to the Electronic Industries Association. The name change will become effective upon approval of a charter revision by the state of Illinois where the Association is incorporated. . . . The State of Illinois approved a charter revision of the 33-year old Association and made effective the change in the name of RETMA to the Electronic Industries Association. The approved charter revision has been returned to the Recorder of Deeds, State of Illinois, as the final step in the procedure.



CEDAR RAPIDS
Annual IRE Picnic: June 22, 1957.

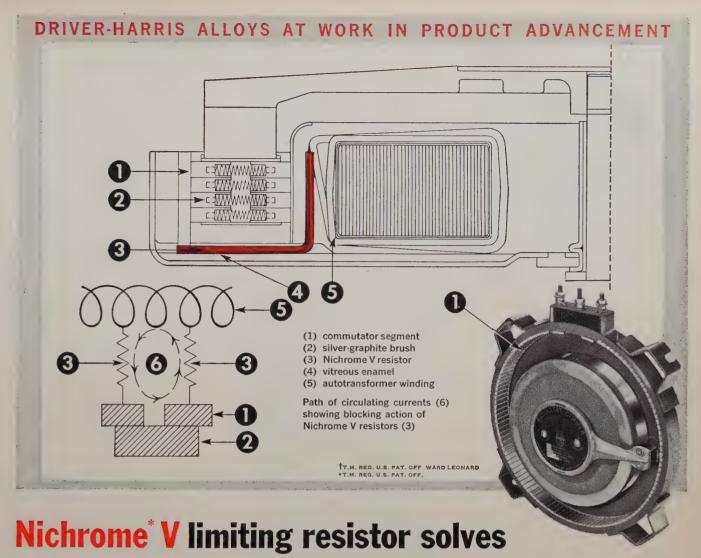
CENTRAL FLORIDA

"Engineering Management of Small Businesses," by Sidney Kaplan, Systems Inc.; May 16, 1957.

"Microlock Extreme Range Tracking and Telemetering," by Dr. E. Rechtin, Jet Propulsion Laboratory; "An Experimental Study of the Hydrodynamics of Liquid Propellant Injectors," by J. H. Rupe; June 20, 1957.

(Continued on page 38A)

36A



### age old brush problem in Ward Leonard Dimmers

This Ward Leonard 6.6 KW Radiastat<sup>†</sup> Dimmer is essentially a specially designed core type autotransformer whose output voltage is linear, furnishing smooth, stepless control from maximum to zero. Other notable features are: Highest rating in smallest size and longer, maintenance-free life.

Nearly all adjustable autotransformers depend upon carbon brushes to limit the short-circuiting current which occurs whenever the brush straddles two segments. However, in the Radiastat Dimmer, circulating currents are kept to a minimum in a unique way, permitting use of self-cleaning, self-lubricating, low resistance silver-graphite brushes.

In the Radiastat, each segment is electrically connected to its respective turn of the winding through a Nichrome V current limiting resistor. During commutation, the main winding is protected against burnout from high short-circuiting currents, thereby eliminating external resistors or high resistance brushes.

These all important resistors (one for each segment) connect to the segments beneath the vitreous enamel and run out and up to connect with the winding. They protect every step of the Radiastat, regardless of the contact arm position—drop a penny or a nail across adjacent segments—there's no pouff! no burnout! The Nichrome V circulating current resistors completely safeguard the unit.

Nichrome V is used because it supplies a specified ohmage in a #10 wire 3%6° long; bonds well with the vitreous enamel; is highly resistant to heat and corrosion, and easily withstands severe current surges.

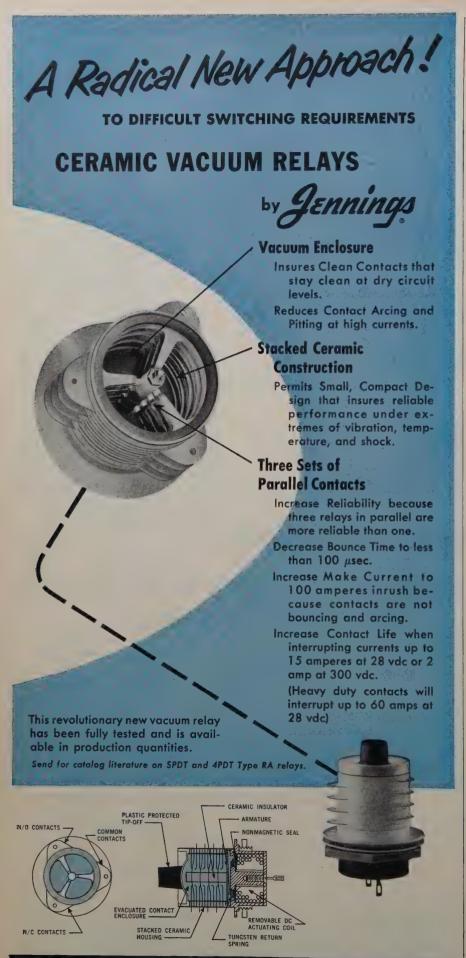
Driver-Harris now produces 132 different high nickel alloys in many different forms and in hundreds of sizes for almost every kind of industrial application. Do you need help with a special alloy? Tell us about it and if we haven't got it, we'll develop it for you.



### Driver-Harris\* Company

HARRISON, NEW JERSEY • BRANCHES: Chicago, Detroit, Cleveland, Louisville

Distributor: ANGUS-CAMPBELL, INC., Los Angeles, San Francisco . . . . In Canada: The B. GREENING WIRE COMPANY, Ltd., Hamilton, Ontario



JENNINGS RADIO MANUFACTURING CORPORATION - 970 McLAUGHLIN AVE. P.O. BOX 1278 - SAN JOSE 8, CALIFORNIA



(Continued from page 36A)

#### CINCINNATI

Banquet and Inspection Trip; June 18, 1957.

#### EL PASO

Ladies Night and Installation of Officers; Joint Meeting with the Las Cruces-White Sands Subsections; July 25, 1957.

#### FORT WORTH

"Bells, Electric Carillons, and Chimes," by Frank Slaymaker, Stromberg Carlson; June 14, 1957.

#### HUNTSVILLE

Tour of CAA Control Tower; Election of Officers; June 27, 1957.

#### INDIANAPOLIS

Tour of FM Radio Station WFMS conducted by Martin K. Williams, WFMS; Election of Officers; July 26, 1957.

#### NORTHWEST FLORIDA

"High Speed Data Transmission—Present & Future Development Programs," by W. H. Deering, American T. & T.; July 16, 1957.

#### PORTLAND

Field Trip conducted by Edward H. Clark, Civil Defense Communications Center; August 8, 1957.

#### SAN DIEGO

"Microwave Amplification by Stimulated Emission of Radiation," by Dr. Harold Lyons, Hughes Research Laboratory; August 6, 1957.

#### SOUTHERN ALBERTA

"The Effects of Electronics on Engineering Practice," by H. A. Hoyles, Canadian Westinghouse; March 11, 1957.

"Point to Point Communication," by Gregory Bayliss, RCA Victor Company; April 10, 1957.

#### SUBSECTIONS

#### EASTERN NORTH CAROLINA

"Aerotron, a new Industry for Eastern North Carolina," by Charles R. Browning, Aeronautical Electronics, Inc.; Election of Officers; July 19, 1957.

#### Northern Vermont

"High Temperature Electronic Amplifiers," by T. N. Stanziola, E. M. Polmer, G. A. Gallent. W. J. Frisby, General Electric Company; August 5, 1957.



#### ANTENNAS & PROPAGATION

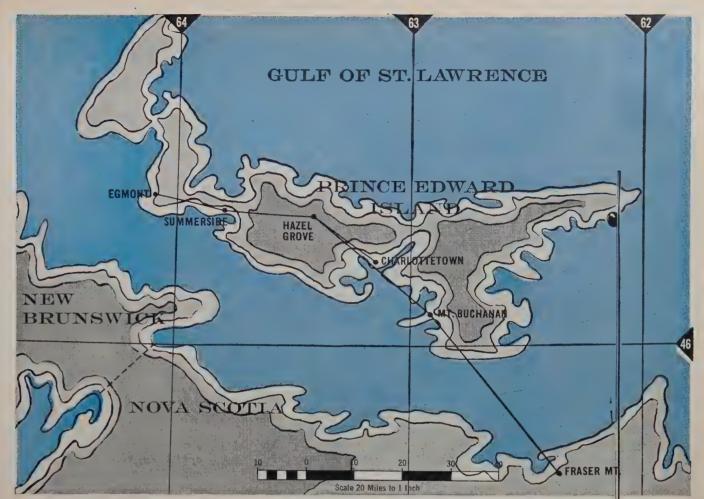
Denver-Boulder-June 3

"Activities of P.G.A.P.," J. W. Herbstreit, N. B. S.

#### Denver-Boulder-June 25

"Activities of the Television Allocations Study Organization," G. R. Town, TASO.

(Continued on page 40A)



### Canadian Telephone Companies order **Collins Microwave Systems**

The Island Telephone Company installs Collins system on Prince Edward Island to replace wire lines, with over-water link to Nova Scotia main land . . . connecting with Collins system owned by Maritime Telegraph & Telephone Limited

On January 6th 1956, a severe storm and icing condition destroyed virtually all wire-line communications on Prince Edward Island, Replacement costs ran into hundreds of thousands of dollars, with service badly disrupted.

Determined that this should not occur again, Engineers at Maritime Telegraph & Telephone Company Ltd. and The Island Telephone Company Ltd., began to lay plans for a modern microwave installation. Having had extensive previous experience with radio systems of many types, the Engineering personnel were in an excellent position to thoroughly analyze the available systems, and a contract was awarded to Collins Radio of Canada.

Two separate systems are involved, one origi-

nating at Fraser's Mountain, Nova Scotia, and terminating at Charlottetown, Prince Edward Island, via two repeaters, the other linking Egmont with Charlottetown via two repeaters.

Unique features include a dual space-diversity overwater path, the transmission of high fidelity multiplex channels for C.B.C. network use and assured circuit continuity through the use of battery-powering and instantaneous hot standby equipment.

These Engineers chose Collins for excellent reasons. Collins Sales Engineers will be pleased to discuss these reasons with you, and to demonstrate the benefits to be derived through the use of these or other Collins quality communications products.



Dual space-diversity overwater path



ollins creative Leader in Communication



COLLINS RADIO COMPANY, CEDAR RAPIDS, 10WA • DALLAS • BURBANK • NEW YORK • WASHINGTON, D. C. • MIAMI • SEATTLE • COLLINS RADIO COMPANY OF CANADA, LTD., TORONTO • COLLINS RADIO COMPANY OF ENGLAND, LTD., LONDON • COLLINS RADIO INTERNATIONAL C.A., PARIS • TOKYO • MIAMI • CARACAS



### MODEL E-2

#### **COMPARISON BRIDGE**



FOR FAST, ACCURATE MATCHING OF

RESISTORS 1 ohm to 5 megohms

CAPACITORS 500 mmfd to 2000 mfd

INDUCTORS 3 millihenrys to 10,000 henrys

- Five Meter Ranges: 1%, 2.5%, 5%, 10% and 25% difference readings at full scale
- Accurate within 0.1% on 1% scale
- Component differences of 1 part in 10,000 can be detected
- Foot operated switch available

\$185.



### SOUTHWESTERN INDUSTRIAL ELECTRONICS COMPANY

P. O. BOX 13058 2831 HOUSTON 19, TEXAS

2831 POST OAK ROAD



(Continued from page 38A)

#### Audio

San Francisco—February 18

"Transistor Amplifying Techniques," Irwin Wunderman, Hewlett-Packard Co.

San Francisco-May 21

"Wide Angle High Frequency Loudspeaker," Leonard Packman, Ampex Corp.

#### COMMUNICATION SYSTEMS

Los Angeles—June 20

"Dynamic Programming and Stochastic Communication Theory," Richard Bellman, Rand Corp.

#### COMPONENT PARTS

Buffalo-Niagara-May 22

"Method of Determining the Therma Condition of Glass Electron Tubes," James Welsh, Cornell Aeronautical Lab.

#### ELECTRONIC COMPUTERS

Los Angeles—June 20

"An Air-Floating Disk Magnetic Memory System," William Farrand, Autonetics; "Computer Control of Industrial Processes," Montgomery Phister, Jr., Ramo-Wooldridge Corp.

#### Los Angeles—July 18

"A New Memory Element Employing Persistent Currents in Superconductors," E. C. Crittenden, Jr., Ramo-Wooldridge Corp.; "Magnacard," Jerome Wiener Magnavox Co.

#### Engineering Management

San Francisco-June 4

"Description of Dalmo Victor Engineering Organization on a Functional Basis," W. F. Gates, Dalmo Victor; "Research Function at Dalmo Victor—Customer and Company Sponsored," G. A. Walters, Dalmo Victor.



The following transfers and admissions have been approved and are now effective:

#### Transfer to Senior Member

Babcock, W. E., Maywood, N. J.
Backman, K. E. H., Melrose Park, Ill.
Beard, C. E., Syracuse, N. Y.
Bein, W., Bronxville, N. Y.
Cash, F. L., Dallas, Tex.

(Continued on page 42A)

### AMP's custom-designed and versatile line

## FOR RADAR AND ELECTRONIC

### EQUIPMENT APPLICATIONS

Ampli-FILM® the all-purpose high voltage dielectric

- ... is not affected by acids or organic solvents
- ... undergoes no distortion under high temperatures and pressures
- ... is readily bonded by adhesives
- ... is easy to handle and fabricate

CAPITRON® WAFER CAPACITOR —Ampli-FILM® dielectric sheets and high conductivity copper electrodes are bonded together under high heat in hydraulic presses using a special non-polar thermo-plastic bonding resin to obtain a solid, void-free sealed capacitor for rugged requirements in high voltage circuits. Having indefinite shelf life, these capacitors are designed for use in oil filled assembly, but also they are well suited for many applications in potted or encapsulated assemblies. They can be supplied in various form factors including curved shapes.

CAPITRON® POWER SUPPLIES —Use of Capitron® Wafer Capacitors enables AMP to provide a wide variety of high voltage power supplies for radar indicators and radar modulators. The small size and light weight of these units dictates their use in many airborne applications. They are supplied either as oil filled metal cased units or as epoxy encapsulated units. AMP's LGH terminals solve high altitude application problems.

#### CAPITRON® ARMORED WAFER CAPACITOR —Factors of this Capacitor are as follows

- Armor type encapsulation to resist extreme thermal and mechanical shock.
- Eliminates high altitude flash-over, as metal terminals are not exposed . . . they are enclosed within the armor encasement.
- Multiple connections to capacitor leads can be made with little or no increase in over-all size of the capacitor.
- · Versatility of design eliminates revamping assembly to accommodate the capacitor.

CAPITRON® PULSE SYSTEM PACKAGE —Charging choke, pulse forming network and pluse transformers are combined in a unit of minimum size and weight to work with a specific magnetron. All components are designed by and manufactured under the direct control of AMP's pulse specialists.

CAPITRON® PULSE FORMING NETWORKS —AMP pulse forming networks can be supplied to meet rigorous specifications with special emphasis on high reliability, small size and light weight for airborne radar applications.











#### AMP INCORPORATED

CHEMICAL AND DIELECTRIC DIVISION 155 Park Street, Elizabethtown, Pennsylvania

Wholly Owned Subsidiaries: Aircraft-Marine Products of Canada Ltd., Toronto, Canada • Aircraft-Marine Products (Great Britain) Ltd., London, England • Societe AMP de France, Le Pre St. Gervais, Seine, France AMP—Holland N. V. 's-Hertogenbosch, Holland

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### METALLIZED ALUMINA ASSEMBLIES

fit your production needs PRECISELY!

Accurate workmanship and highstrength bonds are the two mostwanted characteristics of metallized ceramic products. Through years of intensive research and development, Stupakoff perfected the techniques by which these characteristics are obtained. Close control of chemical reactions, metallic deposits, firing atmosphere and temperature, and certain other operations assures strong, tight ceramic-to-metal bonding. Skillful workmanship and modern manufacturing equipment and processes guarantee the accuracy and dependable uniformity of the

products.

Representative examples of Stupakoff Metallized Ceramics are shown above. They are held to tolerances as close as  $\pm .005$  in. and made for assembly by either hard or soft soldering as required. Strict torque requirements can be met if necessary. Many parts are copper plated to reduce oxidation.

We invite you to make use of Stupakoff's engineering facilities to develop metallized ceramic parts that are precisely right for your assemblies!

STUPAKOFF DIVISION OF

WRITE DEPT. IRE LATROBE, PENNSYLVANIA

### The CARBORUNDUM Company



(Continued from page 40A)

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Schwartz, H. H., Montreal, Que., Canada
Sheriff, D. R., Endicott, N. Y.
Srirama Rao, M., Ottawa, Ont., Canada Steele, E. L., Phoenix, Ariz. Strauss, L., New York, N. Y. Sturgeon, W. S., Great Neck, N. Y. Tanabe, Y., Tokyo, Japan Timmerman, H. A., Vallejo, Calif. Trinkaus, J. W., Bayside, N. Y. Underhill, J. T., San Diego, Calif. Waters, W. P., Los Angeles, Calif.

#### Admission to Senior Member

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#### Transfer to Member

Amling, J. L., Brooklyn, N. Y. Appleberry, T. K., Rome, N. Y. Arnold, D. T., Palo Alto, Calif. Arthurs, E., Cambridge, Mass. Bangs, G. A., Jr., Van Nuys, Calif. Beebe, J. A., Independence, Mo. Berube, R. L., Montreal, Que., Canada Brunt, N. F., San Diego, Calif. Butterworth, G. S., Cincinnati 36, Ohio Carter, F. W., Whippany, N. J. Cassedy, E. S., Jr., Baltimore, Md. Cox, L. G., Ottawa, Ont., Canada Darrow, F. M., Rome, N. Y. Data, C. D., Redwood City, Calif. Davis, D., Rye, N. Y. Dieter, N. H., Jr., Pleasantville, N. Y. Dugan, J. F., Pittsburgh 52, Pa. Dunlop, D. P., Deep River, Ont., Canada Erhart, D. L., Detroit, Mich. Eshbach, J. R. Schenectady N. Y Eukel, W. W., Walnut Creek, Calif. Fischer, E., Kansas City, Kan. Fong, K., Syracuse 10, N. Y. Foss, M. L., Twin Falls, Idaho Frankos, D. T., Canoga Park, Calif. Frederico, J. C. B., Rio de Janeiro, Leme, Brazil

Frieling, E., North Syracuse, N. Y. Gahn, D. E., Hicksville, L. I., N. Y. Gandhi, C. S., Fort Bombay, India Gentry, F. E., Lyons, N. Y. Gerould, L. D., Johnson City, N. Y. Goldberg, P. A., Seattle, Wash. Graf, C. R., San Antonio, Tex. Graham, J. M., Jr., Los Angeles, Calif. Grande, V. J., Palo Alto, Calif. Hacker, S. J., Bloomfield, N. J. Halliday, R. G., Gardena, Calif. Hedgcock, W. T., Jr., Cedar Rapids, Iowa Heflich, G. B., North Bergen, N. J. Heinrich, B. F., East Detroit, Mich. Hershenson, L. H., Lancaster, Pa. Horton, G. L., Wantagh, L. I., N. Y. Houck, G. S., Columbus, Ohio Hutchinson, D. F., Altamont, N. Y. Kasowski, S. E., Camden, N. J. Kass, J. S., East Orange, N. J. Kennedy, C. B., Los Angeles, Calif. Kiblinger, W. H., Woodbridge, Va. Kim, P. S., China Lake, Calif. Kingston, R. H., Cambridge, Mass. Knepper, R. C., Anaheim, Calif. Leech, E. R., Portland, Ore. Loftus, J. A., Philadelphia, Pa. Mahoney, E. H., Tulsa, Okla. Mancino, V. J., Red Bank, N. J. Martin, J. E., Red Bank, N. J. McClure, R. E., Great Neck, L. I., N. Y. McFatridge, J. E., Detroit, Mich. Mitchell, J. R., Walnut Creek, Calif. Molby, L. H., Kansas City, Kan. Monroe, K. E., Ypsilanti, Mich. Moore, L. R., St. Laurent, Montreal, Que., Canada

Mudgett, W. L., Bedford, Mass. Nye, J. W., Riverdale, Md. Omoth, M. J., Seattle, Wash. Orr, L. W., Ann Arbor, Mich. Peabody, S. J., Phoenix, Ariz. Pettersen, R. J., Kitchener, Ont., Canada Pollard, W. J., Janesville, Wis. Potosky, M., Levittown, Pa. Praeg, W. F., Vancouver, B. C., Canada Priart, M. A., Nanaimo, B. C., Canada Quigg, K. R., San Diego, Calif. Radcliffe, A. J., Jr., Chicago, Ill. Ramstedt, C. F., Pasadena, Calif. Raskhodoff, N. M., Cheverly, Md. Rector, J. D., Cedar Rapids, Iowa Ross, H. C., West Covina, Calif. Sapp, E. F., Jr., Valparaiso, Fla. Schupp, A. A., Jr., Ann Arbor, Mich. Serang, A. M., Menlo Park, Calif. Sharp, E. D., Rome, N. Y. Shoucair, S. F., Beyrouth, Lebanon

(Continued on page 52A)



#### SOLVES RELAY ENVIRONMENTAL PROBLEMS

Unique Balanced-Armature Relays meet all requirements of the most exacting operating environments - shock, acceleration, vibration and high temperatures.

In the Leach Balanced-Armature Relay, shock and vibration forces cannot move the relay armature. This eliminates faulty operation of contacts during extreme vibration and acceleration.

These Leach Relays meet or exceed requirements of MIL-R-5757, MIL-R-6106, MIL-E-5272. Typical ratings include: vibration. 20 G's to 500 cps (higher ratings available); shock and acceleration, more than 50 G's; temperature,  $-50^{\circ}$  to  $+125^{\circ}$ C; life, 50,000 continuous operations minimum at rated load; available 28 vac. 115 vac, 400 cps operation. At right is Leach 9226, 1.49x1.49x 1.68 inches.



Leach has gained a unique reputation for creating reliable relays, custom-tailored to solve specific circuitry problems. Write for your copy of the Leach Balanced-Armature Relay Catalog.





LEACH RELAY DIVISION

5915 Avalon Blvd., Los Angeles 3, California

District Offices and Representatives in Principal Cities of U.S. and Canada



your production line.

if it's worth engineers' time

it's worth engineered wire



ONE SOURCE ONE QUALITY

10-I

Magnet Wire • Lead Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable



### NEWS and NEW PRODUCTS

OCTOBER 1957



#### Frequency-Period Counter

The Computer-Measurements Corp., 5528 Vineland Ave., North Hollywood, Calif., has recently announced the availability of their Model 203A Frequency-Period Counter.



This new instrument offers 0 cps to 1 mc direct reading operation for frequency and period (1/frequency) measurement. Other typical applications of the Model 203A are measurement of pressure, temperature, velocity, acceleration, flow RPS, RPM, displacement, and so forth, which may be measured with suitable transducers. The instrument also serves as a secondary frequency standard.

The major features are: Continuously adjustable trigger level control permits full rated sensitivity at any voltage level between -300 and +300 volts. Small voltage increments ordinarily masked by attenuators are easily selected. Simplified color-coded controls and direct read-out in kc, mc, sec, or millisec, with automatic decimal point indication.

Oscilloscope marker signal facilities trigger level adjustment for amplitude discriminated in frequency or period measurement. Binary coded output for operation of digital printers and other accessories. Time base range of 10 microseconds to 10 seconds in decade steps (frequency), 1 and 10 cycles (period).

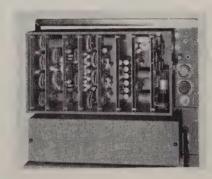
Complete catalog information and detailed specifications on the new CMC, Model 203A are available on request to the firm.

### Transistorized SSB Transceiver

The 464-TR Transceiver developed by Erco Radio Labs., Inc., 637 Stewart Ave. D., Garden City, L.I., N.Y., will provide reliable voice communication chan-

These manufacturers have invited PRO-CEEDINGS readers to write for literature and further technical information, Please mention your affiliation.

nels over existing telephone or power lines where additional talking facilities are required. It can be used on any frequency between 5 and 200 kc where the total attenuation does not exceed 80 db with each voice channel occupying a bandwidth of 3000 cps.

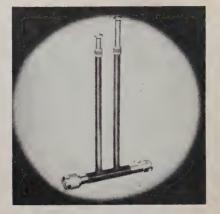


Plug in modular construction together with printed circuitry is employed and the complete transceiver is mounted on a standard  $8\frac{3}{4}$  by 19 inch panel. When transmitting, a +15 dbm carrier is used for selective calling and receiver ABC control and at full modulation, the sideband power is +26dbm or 400 milliwatts peak envelope power. Because the transceiver is completely transistorized, the total battery drain from a 24 volt dc source in only 400 milliwatts when receiving and 4 watts when transmitting. Selective calling components are mounted on an adjacent panel.

The equipment is applicable to any service where physical circuits are limited by line noise or overloading and will provide additional talking circuits at a fraction of the cost of installing additional physical circuits.

#### Double Stub Tuner

The double stub tuner produced by Uniwave, Inc., 2 Marine St., Farmingdale, L.I., N.Y., is an impedance matching instrument capable of performing a variety of electronic functions. An interesting feature of the unit is a pair of collets which locks the tuner securely in any pre-set position.

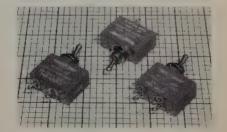


Designated Model DS-1-12, this device has an impedance of 50 ohms and a frequency range of 1,000 to 12,000 mc. It can be used to match wide ranges of impedance in a transmission line system or introduce a similar range of impedance into otherwise matched systems. It can also provide maximum power transfer between an oscillator and its load. In addition, it can function as a sensitive crystal detector, as a square law bolometer mount or as a frequency multiplier.

For further details contact Uniwave.

### Shunt and Relay Style Circuit Breakers

Airpax Products Co., Ft. Lauderdale, Fla., announces availability of shunt and relay style circuit breakers. These new units use the same magnetic time-delay trip mechanism as the series style breakers. Trip level is independent of temperature in all three styles.



In series style breakers, the release coil is in series with the contacts and operates when the load current exceeds 135 per cent of normal rating. In shunt style breakers the release coil can be shunted externally: for example, by a rheostat to adjust trip level. In relay style breakers, the release coil is entirely independent of the

(Continued on page 50A)

PROCEEDINGS OF THE IRE October, 1957

# Announcing the Raytheon

-a new type of broadband,

high power.....



The Amplitron is a new type of tube developed by Raytheon, capable of power amplification at microwave frequencies. Amplification is obtained over a broad range of frequencies with no mechanical or electrical adjustments required. This device is a derivative of the magnetron and retains many of its advantages—such as high operating efficiency, construction simplicity, small size, light weight, low operating voltage. Where efficiency counts in high-power systems, the broadband Amplitron has applications of major significance.

The Amplitron uses crossed electric and magnetic fields, a reentrant beam produced by a magnetron-type cathode, and a non-reentrant broadband circuit matched at either end to external circuits.



HAS THE KNOW-HOW AND EXPERIENCE REQUIRED TO PRODUCE CUSTOM-BUILT DELAY LINES TO YOUR EXACTING SPECIFICATIONS.

1st in sales!

1st company devoted exclusively to the manufacture of delay lines!

1st in research, design and development of custom-built delay lines!

1St to submit the most definitive laboratory reports with all custom-built delay line prototypes!

**ken**-vision, knowledge, perception... as, ESC has the ken to produce the finest custom-built delay lines in use today.

Exceptional employment opportunities for engineers experienced in pulse techniques.



#### CORPORATION

534 Bergen Boulevard, Palisades Park, New Jersey





These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 50A)

highly reliable, leak-tight hermetic seal with excellent electrical characteristics in continuous operations at temperatures up to  $+700^{\circ}$ F.

"Ceramicite" is available in two forms: (1) as pre-formed pieces, ready for firing by the user in fabrication of seal components and (2) completed seal components, such as single and multiple pin terminals and headers.

Further information regarding "Ceramicite" seals appears in CEC Bulletin 1587, available from the firm.

(Continued on page 60A)



(Continued from page 43A)

Small, C. E., Riverton, N. J. Solomon, S. M., Brooklyn, N. Y Spencer, D. K., Hagerstown, Md. Sprinz, E., Los Angeles, Calif. Starobin, A. F., Hyattsville, Md. Sterrett, J. E., Stanford, Calif. Taylor, C. K., Tucson, Ariz. Terkanian, H., Lexington, Mass. Tkatsh, M., Kyryat, Motzkin, Israel Tong, S. R., Monrovia, Calif. Tracy, R. C., Columbus, Ohio Vesser, W. C., Los Angeles, Calif. Whistler, W. T., Syracuse 6, N. Y. Wiedman, R. E., Saint Paul, Minn. Willard, J. H., Denver, Colo. Wilson, M. F., Cedar Rapids, Iowa Wilson, S. S., St. Laurent, Que., Canada Zieman, H. E., Lexington, Mass. Booher, W. R., Middletown, Ind.

#### Admission to Member

Andreasson, R. I., Santa Monica, Calif. Ayukawa, K., Cardinal Heights, Ont., Canada Baker, B. A., Berwyn, Pa. Banerjee, A., Calcutta, India Barnabic, E. V., New York, N. Y. Berg, S., Chicago, Ill. Betts, M. D., Rockport, Mass. Bhavnani, K. H., Pittsburgh, Pa. Binns, F. D., Nashville, Tenn. Blankenship, A. C., Silver Spring, Md. Blitch, M. G., Robertson, Mo. Bloom, V. A., Rego Park, Queens, N. Y. Boss, W. O., W. Collingswood, N. J. Bossert, A. J., Jr., Kansas City, Mo. Brown, R. F., Jr., Arlington, Va. Brown, W. C., Dayton, Ohio Bryan, C. W., Dayton, Ohio Bryant, W. E., Jr., Panama City, Fla. Buren, W. E., Owensboro, Ky. Burtis, S. Fr., Jr., Swarthmore, Pa. Cacioppo, A. J., Cuyahoga Falls, Ohio Cafaro, J. A., Merchantville, N. I. Carruthers, W. E., Montreal, P. Q., Canada Castelli, H. B., Wichita, Kan.

(Continued on page 54A)

#### A NEW Amperex FRAME GRID TUBE

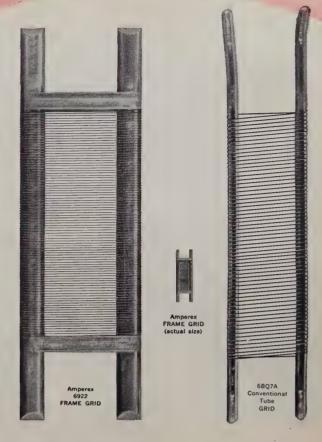
It's the frame grid construction

that makes the difference...

- Higher transconductance
- Tighter  $G_m$  tolerance (all tubes  $-G_m = 12,500 + 2500$ )
- Low transit time
- Low capacitances
- Better grid and plate current division

#### **ADDITIONAL FEATURES**

- Passive cathode for long life
- Ruggedized construction
- New 'dimple' anode



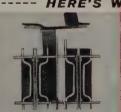
In the Amperex 6922 Frame Grid, note the fine wires under tension with the tight tolerances of the grid-to-cathode spacing determined by the carefully controlled diameter of the centerless ground grid-support rods and the frame cross-braces between these rods.

In conventional tubes, the grid dimensions are obtained by stretching on a mandrel. The tolerance of grid-to-cathode spacing is therefore dependent upon this operation as well as the tolerances of the holes in the top and bottom mica rod supports.



ruggedized, low-noise, broad-band twin triode

HERE'S WHAT THIS MEANS TO THE DESIGN ENGINEER...



- Reliable radar cascode stages
- Higher speed computer operation
- Lower noise, higher gain RF amplifiers
- Minimum guaranteed 10,000 hour life

#### TYPICAL OPERATION

Plate Supply Voltage 100 volts
Grid Supply Voltage +9 volts
Cathode Bias Resistor 680 ohms
Plate Current 15 ma
Transconductance (min. 10,500; max. 15,000)
12,500 umhos

Amplification Factor 33
Equivalent Noise Resistance 300 ohms
Grid Voltage (rms) 0.75 volts



#### ask Amperex

about "premium quality" frame grid tubes for communication, instrumentation and industrial applications.

Amperex ELECTRONIC CORPORATION, 230 Duffy Avenue, Hicksville, L. I., N. Y.



## signal with the click of a switch!

### MODEL WWVC FREQUENCY COMPARATOR ENDS "SEARCHING" FOR THE STRONGEST STANDARD SIGNAL

This new tool can save you valuable calibration time. With it you can quickly find the strongest signal available at any moment from the National Bureau of Standards – without searching.

A five-position dial switches precisely to any standard frequency -2.5, 5, 10, 15 or 20 MC—each crystal controlled. Built-in oscilloscope and speaker make measurements easy. Model WWVC includes comparator function selector, Collins plug-in filter for high selectivity, automatic gain and volume controls, and adjustable threshold control which eliminates noise and other

modulation in tick position. Calibrate any frequency accurately and quickly with the Model WWVC. Write for Bulletin C-1.



**MODEL WWVC** standard frequency comparator



### **SPECIFIC PRODUCTS**

p.o. box 425; 21051 Costanso, Woodland Hills, California



(Continued from page 52A)

Chambers, H. L., Berwyn, Ill. Chauhan, M. V., Rajahmundry, India Clark, W. E., Dallas, Tex. Cleary, D. R., Kansas City, Md. Comparetta, T. J., Bayshore, L. I., N. Y. Copeland, P. L., Chicago, Ill. Cottin, R. S., New York, N. Y.
Couture, C., Jr., Charleston, S. C.
Cowan, C. F., Torrance, Calif. Cummings, J. R., Yonkers, N. Y. Deyton, J. B., Jr., Charlotte, N. C. Eckert, F. A., Levittown, Pa. Ernst, W. P., Hopelawn (Perth Amboy), N. J. Evans, G. L., Los Angeles, Calif. Evans, T. R., Bethesda, Md. Flannell, C. F., Port Chester, N. Y. Frantz, E. C., Woodbury, N. J. Friedmann, E., Riverside, Calif. Gaffney, J., Wappingers Falls, N. Y. Gellhaus, K. M., Philadelphia, Pa. Germain, J. M., Dallas, Tex. Gisonno, G. L., Asbury Park, N. J. Goodberlet, E. F., St. Louis, Mo. Gusman, L., New York, N. Y. Haaland, C. M., Gainesville, Fla. Hanks, C. L., Columbus, Ohio Hanrahan, J. A., New York, N. Y. Hauer, C. A., Philadelphia, Pa. Havranek, W. C. R., Cambridge, England Hawkins, J. K., Manhattan Beach, Calif. Hayata, T. A., Los Angeles, Calif. Hayes, W. B., Palos Verdes Estates, Calif. Hazlett, W. T., Endicott, N. Y. Hecq, Y. V., Brussels, Belgium Henry, V. F., Lanham, Md. Herbert, M. B., Dayton, Ohio Heyne, M. W., Bellevue, Neb. Hilson, E. A., Ft. Walton Beach, Fla. Hoving, H. R., Manhattan Beach, Calif. Hurd, C. D., El Paso, Tex. Hvatum, H., Gothenburg S., Sweden Johnson, A. F., Lexington, Mass. Johansen, D. E., Cambridge, Mass. Kahn, W. M., Newton Highlands, Mass. Katell, E., New York, N. Y.
Khan, A. H., Hertfordshire, England
Klimpl, E. W., San Francisco, Calif.
Lawson, A. C., Paoli, Pa.
Leake, B. W., Wayland, Mass. Linn, F. S., Jr., Santa Clara, Calif. Lohman, A. F., Pleasantville, N. Y. Malcolm, D. H., Minneapolis, Minn. Marcucci, R. L., Garland, Tex. Mc Bain, H. F., Maracaibo, Venezuela, S. A. McGolrick, J. E., Rockville, Md. McLane, S. B., Jr., Davidson, N. C. Meyer, B. L., Bloomington, Minn. Milowitz, P., Philadelphia, Pa. Moher, R. B., Toronto, Ont., Canada Montgomery, W. C., Franklin, Tenn. Morrison, R. E., Emporium, Pa. Moss, H., New York, N. Y. Naylor, D. A., Takoma Park, Md. Neeland, F., Philadelphia, Pa. Newgent, W. L., San Diego, Calif. Nichols, B. E., Wellesley Hills, Mass. Nilsson, B. G., Rollings Hills, Calif. Norton, F. R., Tucson, Ariz. Nowalk, T. P., Youngwood, Pa. Olson, R. E., San Bruno, Calif. Olving, S., Gothenburg, Sweden Oppenheimer, E. P., Moline, Ill. Owen, J. G., Dallas, Tex. Owen, K., Binghamton, N. Y. Patchell, T. A., Havertown, Pa. Pegg, B. A., Glen Burnie, Md. Pennington, E. T., Huntington, Va. Phillips, J. L., Jr., Dallas, Tex.

(Continued on page 58A)



#### FILLING THE GAPS IN FREEDOM'S FENCE

The possibility of low-level bombers, slipping through the continental radar fence, has been the cause of much concern in our Air Defense Command. But a new "gap filler" radar eliminates the shadow areas caused by the earth's curvature and irregularities of terrain...helps give instant warning of the approach of intruding aircraft.

Vital in the chain of "gap filler" radar sites is a Varian Type VA-87 klystron amplifier, sending out a million-watt pulse of power a thousand times a second on a 24-hour-a-day basis. It provides the absolute dependability necessary to our national security. Result—a radar that will operate fully automatically, for prolonged periods of time, with neither operating nor maintenance personnel at the radar site.

Complete dependability is a characteristic of *all* Varian klystrons, along with extreme ruggedness, frequency stability, and outstandingly long life in service. Write the Varian application engineering department for complete specifications on the Type VA-87, or ask your Varian representative for a copy of the Varian Catalog.

Varian is now building more than 1,000 VA-87 klystron amplifiers for the United States Air Force, for use in the AN/FPS-18 gap filler radar systems being manufactured by Bendix Aviation Corp.



Frequency range: 2800-2900 Mc Peak power output: One megawatt Duty cycle: ,003 Power gain: 60db

THE MARK OF LEADERSHIP



KLYSTRONS, TRAVELING WAVE TUBES, BACKWARD WAVE OSCILLATORS, LINEAR ACCELERATORS, MICROWAVE SYSTEM COMPONENTS, R. F. SPECTROMETERS, MAGNETS, MAGNETOMETERS, STALOS, POWER AMPLIFIERS, GRAPHIC RECORDERS, RESEARCH AND DEVELOPMENT SERVICES

PROCEEDINGS OF THE IRE October, 1957 57A



### FREED 1110-AB INCREMENTAL INDUCTANCE BRIDGE

AND ACCESSORIES

Accurate inductance measurement with or without superimposed D.C., for all types of iron core components.

- INDUCTANCE 1 Millihenry to 1000 Henry
- FREQUENCY 20 to 10,000 Cycles
- ACCURACY 1% to 1000 Cycle, 2% to 10KC
- CONDUCTANCE 1 Micromho to 1 MHO
- ''Q'' 0.5 to 100
- SUPERIMPOSED D.C. Up to 1 Ampere
- DIRECT READING For use by unskilled operators.

ACCESSORIES AVAILABLE:

1140-A Null Detector 1210-A Null Detector - V.T.V.M. 1170 D.C. Supply and 1180 A.C. Supply.

### FREED VARIABLE TEST VOLTAGE MEGOHMMETER NO. 1620



The Freed Type 1620 Megohmmeter is a versatile insulation resistance measurement instrument with a continuously variable DC test potential from 50 to 1000 volts.

Components such as transformers, motors, printed circuits, cables and insulation material can be tested at their rated voltage and above, for safety factor.

- Resistance 0.1 megohms to 4,000,000
- Voltage -- variable, 50 1000 volts.
- Accurate plus or minus 5% on all ranges.
- Simple for use by unskilled operators.
- Safe high voltage relay controlled.
- Self. contained AC operated.

#### OTHER MEGOHMMETERS AVAILABLE

Type 1620C MEGOHMMETER — a type 1620 with additional circuitry for testing capacitors. Type 1020B MEGOHMMETER — a 500 valt fixed test potential. Range 1 megohm to 2 million megohms. Type 2030 PONTABLE MEGOHMMETER —

Type 2030 PORTABLE MEGOHMMETER — battery operated 500 volt test potential. Range 1 megohm to 10 million megohms,

Send for NEW 48 page transformer catalog. Also ask for complete laboratory test instrument catalog.

### FREED TRANSFORMER CO., INC.



(Continued from page 54A)

Pratt, D. E., Fairfax, Va. Prohaska, C. R., Wright-Patterson AFB, Ohio Race, H. C., Norwood, Mass. Ramamoorthy, C. V., Minneapolis, Minn. Rea, W. P., Jr., Inglewood, Calif. Reese, H. E., Jr., Paoli, Pa. Reiner, W. D., Poughkeepsie, N. Y. Retzlaff, D., Dallas, Tex. Reynolds, K. A., St. Rose, Laval County, Que., Canada Ripp, H., Hastings-On-Hudson, N. Y. Roesler, L., Dayton, Ohio Rosen, S., Syracuse, N. Y. Rumble, W. G., Haddon Heights, N. J. St. John, C. G., Rome, N. Y. Sample, J. G., Dayton, Ohio Schlemm, N. H., Jr., Silver Spring, Md. Schubert, R. A., Dale City, Calif. Schwender, L. D., Huntington, Va. Segal, R. E., Los Angeles, Calif. Shames, J., Nutley, N. J. Silverschotz, S. B., New York, N. Y. Silverstone, D. M., Bridgeport, Conn. Simon, D. H., Woburn, Mass. Simpson, L. F., Wichita, Kan. Smith, W. C., Wright Patterson AFB, Ohio Snejdar, V., Praha, CSR Solomon, S. S., Chicago, Ill. Spencer, J. M., Jr., Mountain View, Calif. Stevens, R. R., Jr., Los Alamos, N. Mex. Stewart, J. B., Madison, N. J. Stokoe, R. H., Ballston Lake, N. Y. Sumner, H. C., Camden, N. J. Teel, W. A., Panama City, Fla. Thomas, A. M., Panama City, Fla.

Tracy, R. A., West Chester, Pa.
Ullman, P. J., Palo Alto, Calif.
Vorobeitchik, J., Bruxelles, Belgique
Wallach, D. M., East Rockaway, N. Y.
Watkins, R. E., Tulsa, Okla.
Watson, R. D., Gardiner, N. Y.
Weinstein, H. N., Tarrytown, N. Y.
Wells, J. F., Lansing, Ill.
Whiteside, D. L., Garland, Tex.
Willows, D. J., Beaconsfield W., P. Q., Canada
Wood, H. H., McMasterville, Que., Canada
Young, D. D., Dayton, Ohio

#### Admission to Associate

Ammon, G. M., Milwaukee, Wis. Andres, R. S., Syracuse, N. Y. Barwicz, W., Warsaw, Poland Black, J. H., Quinton, Va. Bronkala, H. J., Minneapolis, Minn. Brown, B. L., Hollydale, Calif. Brown, R. J., Van Nuys, Calif. Bryer, R. L., Jr., Dayton, Ohio Carpenter, R. D., Wellfleet, Mass. Chinn, H. R., Victoria, S. E., Australia Codina, J. G., Jackson Heights, L. I., N. Y. Dallyn, H. E., Toronto, Ont., Canada Das Gupta, P. C., Berlin-Charlottenburg, Germany Dean, M. H., Jacksonville, Fla. Diamond, L. R., Buffalo, N. Y Dubesteanu, J., Washington, D. C. Endsley, D. L., Albuquerque, N. Mex. Feld, R., Haifa, Carmel, Israel Fitzroy, D. C., San Rafael, Calif. Forell, H. K., Huntingdon Valley, Pa. Gethin, S. A., Flushing, L. I., N. Y. Grazioli, R., Firenza, Italy Ham, B. D., Akron, Ohio Harcar, A. R., San Francisco, Calif. Hopkins, J. A., Gimli, Man., Canada

(Continued on page 60A)





MPE MAKES NEW DESIGNS RAPIDLY TWT'S BWO'S

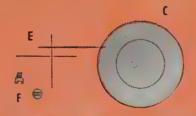
SERVING YOU THE FINEST

YOUR SPECS.

OUR SOLENOIDS
ARE MADE TO
THE EXACTING
DESIGN REQUIRED TO
OCUS TRAVELING
WAVE TUBES, AND
HAVE PROVEN SO
IN MANY PRODUCTION RUNS.

MENLO PARK ENGINEERING

723 HAMILTON AVE. MENLO PARK, CALIF. DAVENPORT 5-8401





illustrated approximately actual size.

# ALSIMAG\* PRECISION CERAMICS

# produced to precision tolerances

New equipment and techniques are constantly added to improve precision. Few people—few engineers are aware of the close tolerances which are now possible. There are 3 main reasons for this progress:

COMPOSITIONS. Widest range in the industry. Some AlSiMag materials are hard as sapphire — more wear resistant than tool steel — and are non-magnetic and chemically inert. New Alumina "super ceramics" perform unbelievable feats of strength, thermal and mechanical shock resistance plus excellent electrical characteristics at ultra high frequencies and temperatures. Improved characteristics promote ruggedization, permit miniaturization.

CONTROLS. In preparation of raw materials, designing and building dies, calculating shrinkages as at every manufacturing step — forming, firing, inspecting. Over 55 years of experience — where precision in ceramics was pioneered!

FINISHING. Equipment plus skill. Every machine for precision finalizing. Thoroughly trained personnel who consider difficult specifications a personal challenge.

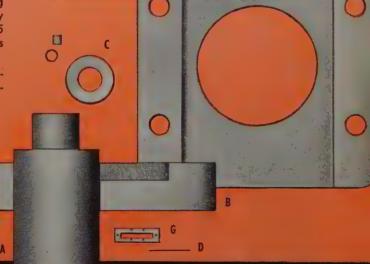


Tell us about your component problems, AlSi-Mag Precision Ceramics may do a better job for you. Send us a blueprint or sketch with an outline of the operating procedure for complete details.

# Do you know.

that ceramics can be supplied, in quantity: To tolerances generally associated with precision metal work.

- A. Pistons and cylinders with maximum clearance of as little as .0015".
- **B.** With faces parallel within .0005".
- C. In flatnesses within light bands.
- D. In thicknesses from .007" up.
- E. In tubular form as small as .015" OD. .008" ID.
- F. Threaded screws as small as 2-56 thread.
- **G.** With drilled holes as small as .010".



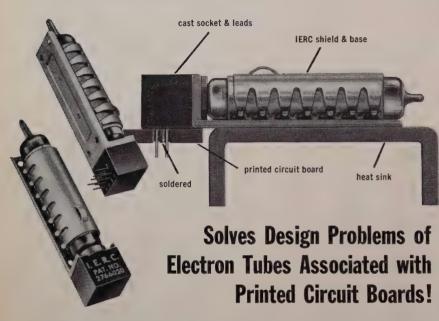
A Subsidiary of Minnesota Mining and Manufacturing Company



CHATTANOOGA 5, TENN. 55TH YEAR OF CERAMIC LEADERSHIP

For service, contact Minnesota Mining & Manufacturing Co. Offices in these cities (see your local telephone directory): Atlanta, Ga. . Boston: Newton For service, contact Minnesota Mining & Manufacturing Co. Offices in these cines (see your local telephone anectory); Atlanta, Co. \* Boston: Newton, Center, Mass. \* Buffalo, N. Y. \* Chicago, Ill. \* Cincinnati, O. \* Cleveland, O. \* Dellas, Texas \* Detroit, Mich. \* High Point, N. C. \* Los Angeles, Calif. \* New York: Ridgefield, N. J. \* Philadelphia, Pa. \* Pittsburgh, Pa. \* St. Louis, Mo. \* St. Paul, Minn. \* So. San Francisco, Calif. \* Seattle, Wash. Canadaf Minnesota Mining & Manufacturing of Canada, Ltd., P. O. Box 757, London, Ont. All other export: Minnesota Mining & Manufacturing Co., International Division, 99 Park Ave., New York, N. Y.

# IERC Heat-dissipating "plug-in" Tube Shields for Printed Circuits!



IERC's latest heat-dissipating tube shields for round button and flat press subminiature electron tubes solve design and performance problems of tubes associated with printed circuit boards. Standard socket and an Epoxy resin are integrally cast to the shield base. Socket leads extend from the Epoxy casting 90° to plane of base permitting direct plug-in to printed circuits for hand or dip-soldering of connections. Bulb temperatures are maintained to within 5°C of the heat sink temperature per watt of heat-dissipation when shields are attached, as suggested, to a heat sink of proper thickness for conduction or hollow duct types permitting air or liquid circulation. IERC's patented design provides maximum cooling, excellent tube retention, shock and vibration protection under severe conditions. Pertinent dimensions are to .1 inch grid layout.



# International



electronic research corporation

145 West Magnolia Boulevard, Burbank, California

**IERC Research and Engineering** experience on improving electron tube life and reliability has won industry-wide acceptance and established IERC as the Authority for the best answers to your tube failure problems. Write today for free information on IERC tube shields—the *only complete line available* for new equipment and retrofitting programs.

Heat-dissipating electron tube shields for miniature, subminiature octal and power tubes



(Continued from page 58A)

Jernigan, E. L., Dallas, Tex. Khalil, A. Y., Alexandria, Egypt Kirkpatrick, A. W., Boulder, Colo. Lang, A. H., New Milford, N. J. Lee, F., San Francisco, Calif. Lehman, D. R., Milwaukee, Wis. Livingston, W. C., Mount Wilson, Calif. Lobel, H., Omaha, Neb. Loch, R. D., Omaha, Neb, Love, W. R., Savannah, Ga. Lowe, A. L., Greensboro, N. C. McClellan, K. C., Dayton, Ohio Muzzio, J. L. R., Sao Paulo, Brazil Nichols, G. E., Glendale, Calif. Oakson, G., Toronto, Ont., Canada O'Connell, P. R., East Longmeadow, Mass. Pikarsky, J., Haifa, Israel Plitch, J., Haifa, Israel Poole, J. F., Gloucester, Mass. Quarta, P., Milano, Italy Rollins, C. W., Ardmore, Okla. Rosenthal, H. A., Palo Alto, Calif. Sherman, H., Fair Lawn, N. J. Siddiqi, M. I., Chelmsford, England Stemme, E., Stockholm, Sweden Striegel, M. E., Milwaukee, Wis. Suminski, H., Arlington, Va. Taylor, R. T., Akron, Ohio Travis, W., Oak Park, Ill. Valentine, D. T., Teterboro, N. J. Wetterau, A., Woodstock, N. Y. White, W. J., Chicago, Ill. Wilkins, J. R., Isle of Palms, S. C. Wilson, C. L., Owing Mills, Md. Wilson, R. P., Taylorsville, Calif. Yoshimura, T., Osaka, Japan Zacher, G. E., Milwaukee, Wis. Zeman, P. A., Towson, Md. Zimmerman, B. L., Alamogordo, N. Mex.



(Continued from page 52A)

#### New Plant for Gibson Electric

Gibson Electric Company announced it has moved its manufacturing facilities and offices from Pittsburgh to a new plant in Delmont, Pa.



Herbert C. Graves, Jr., president, stated that construction of a modern, 26,000-square-foot building has been completed on Old William Penn Highway. All of Gibson's manufacturing, research, purchasing, marketing, sales, and office facilities, formerly located at 8350 Frankstown Avenue, Pittsburgh 21, Pa., are housed in the new building.

Preparing to celebrate its 25th anniversary in 1958, Gibson is now one of the nation's large producers of electrical contacts. Gibson is credited with pioneering powdered metal "ductile" electrical contacts to provide combinations of physical and electrical properties not possible with alloyed materials.

(Continued on page 62A)

# now! 400 mA 600 volts PIV

in a glass package

immediately available in production quantities

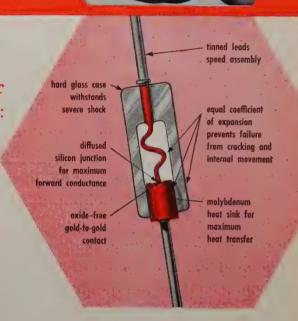




a new solution to your inventory and spare parts problems:

You can now get big voltage operation (to 600 V) plus a new high in forward conductance (400 mA) along with a 2 million-to-1 forward-to-reverse current ratio... from new TI diffused silicon glass diode/rectifiers! This means you can eliminate scores of diodes and rectifiers from your inventories... and stock only five TI diode/rectifiers for virtually all your requirements. For your magnetic amplifiers, modulators, demodulators, networks or subminiature power supplies, this new TI diode/rectifier series—with its extremely wide 225 to 600 voltage range—will meet your exacting circuitry needs.

To see why, check these significant parameters:



#### maximum ratings

	1N645	1N646	1N647	1N648	1N649	
Peak Inverse Voltage at -65 to +150°C	225	300	400	500	600	V
Average Rectified Forward Current at +25°C	400	400	400	400	400	mA
Average Rectified Forward Current at +150°C	150	150	150	150	150	- mA
Recurrent Peak Forward Current at +25°C	1.25	1.25	1.25	1.25	1.25	amp
Surge Current, 1 Second DC at +25 to +150°C	3	3	3	3	3	Amp
Power Dissipation at +25°C	600	l 600 l	600	600	600	mW

# specifications

Minimum Breakdown Voltage at +100°C	275	360	480	600	720	l v
Maximum Reverse Current at PIV at +25°C	0.2	0.2	0.2	0.2	0.2	μА
Maximum Reverse Current at PIV at +100°C	15	15	20	20	25	μА
Maximum Voltage Drop at $I_0 = 400$ mA; at $+25^{\circ}$ C	1.0	1.0	1.0	1.0	1.0	V

Put TI diode/rectifiers to work for you now! Write today for Bulletin No. DLS-770



GENERAL ELECTRIC

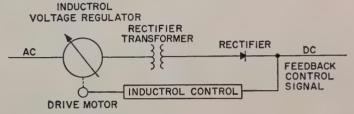
# VOLTAGE REGULATION IDEA FILE

by C. A. Neumann



# ENGINEERING DESIGN IDEA: A.C. Controls D.C.

General Electric Inductrol\* a-c induction voltage regulators can control d-c voltage or current. Here's how:



Inductrol regulators compensate for a-c line variations, rectifier aging effects, regulation as d-c load current varies, hold voltage (or current) to  $\pm 1\%$ .

**DESIGN BENEFITS:** Inductrol regulator drift-free controls always keep voltage settings at desired level. Cost is low.

#### RADAR APPLICATION IDEA:

New England radar manufacturer uses three single-phase Inductrol voltage regulators to give precise individual phase regulation, hold voltage to  $\pm 1\%$ . In addition a three-phase, motor-operated, manually-controlled Inductrol regulator is used for tube warm-up. Power can be increased by raising voltage from 0 to 600 in either two seconds or 30 seconds.

**DESIGN BENEFITS:** Easy-to-install, Inductrol voltage regulators introduce no waveform distortion into electronic systems.

### COMPUTER APPLICATION IDEA:

Massachusetts computer manufacturer got line stability and proper tube warm-up by using both voltage stabilizer and voltage regulator. One Inductrol voltage regulator now does both jobs.

**DESIGN BENEFITS:** Inductrol voltage regulators have an excellent space factor, require little maintenance. They neither affect, nor are affected by, system power factor.

### **HEAT TEST IDEA:**

Boston electronics firm uses battery of infrared quartz lamps to simulate missile in-flight heat conditions. Lamps, energized suddenly on this 208-volt circuit produced rapid heat, but lack of warm-up time caused expensive lamp mortality. A complicated and expensive wiring-switching arrangement was considered, discarded in favor of 3-phase automatic Inductrol voltage regulator.

**DESIGN BENEFITS:** Inductrol voltage regulators have no brushes to maintain or replace; are rugged, designed for long life; are extremely accurate and reliable.

FOR MORE INFORMATION write Section 425-8, General Electric Company, Schenectady 5, N. Y.

\*Trade mark of General Electric Company for Induction Voltage Regulators.

Progress Is Our Most Important Product



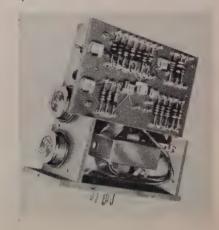


These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 60A)

# 20-Watt Transistorized Amplifier

A 20-watt transistorized plug-in amplifier for public address systems that replaces units more than eight times its size is now available from **Universal Transistor Products Corp.**, 143 E. 49th St. New York 17, N. Y.



The unit occupies 50 cubic inches. It comes with built-in equalization, has a signal to noise ratio greater than 30 db, and less than 3 per cent harmonic distortion at the low frequency end.

Input impedance is matched to the tape recorder magnetic playback head. Frequency spectrum from 50 to 20,000 cps available.

The amplifier includes peak clipping and gain control, and meets military environmental specifications.

# Magnetic Amplifiers Elects New Officers



Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y., announced the election to the Presidency of Harold A. Goldsmith (left) and Executive Vice-Presidency of Herbert Herz (right), both

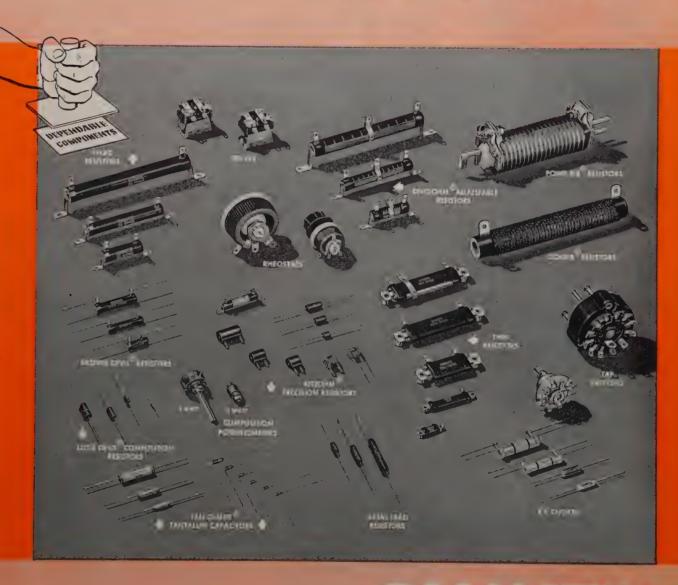
(Continued on page 64A)

# OHMITE

the complete line of

Long life and dependability are synonymous with the name Ohmite. When you specify Ohmite components... you build reliability into your product. This reliability is backed by Ohmite's continuing research programs which explore new product ideas, improve present products, and develop more efficient manufacturing processes. All this plus the fact that Ohmite is the world's leading specialist in the manufacture of power-type resistance components—high quality rheostats and wire-wound resistors in the most complete range of sizes and types available to industry. Reliability is also characteristic of Ohmite tap switches, precision wire-wound resistors, molded composition resistors and potentiometers, general-purpose relays, subminiature tantalum capacitors, and R. F. chokes. Write on company letterhead for the complete Ohmite Catalog and Engineering Manual.

# industry-preferred COMPONENTS



BE RIGHT WITH

OHMITE®

RHEOSTATS • RESISTORS • RELAYS • TAP SWITCHES • TANTALUM CAPACITORS





These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 62A)

formerly Vice-Presidents of the company. By a Board of Directors resolution the offices of President and Executive Vice-President are set up to rotate on a yearly basis between the two founders of the company. S. M. Kellen, formerly President was elected Chairman of the Board of Directors. Magnetic Amplifiers, Inc. has main office and plants in New York 55, N. Y. and a West Coast Division in El Segundo, Calif.

### Richmond Retires from General Radio

Harold B. Richmond, for the past thirteen years Chairman of the Board of the **General Radio Co.,** 275 Massachusetts Ave., Cambridge, Mass., retired on June 30.

Mr. Richmond joined the General Radio Co. as an engineer in 1919 and two years later was elected its Secretary. He became Treasurer in 1926, which position he held until his election as Chairman of the Board of Directors. His principal interests have always been in the business and managerial affairs of the Company, but he has found time for notable work in outside affairs.

He has been director and president of the Radio Manufacturers Association (now RETMA); director, president, and chairman of the Scientific Apparatus Makers Association; director of the Liberty Mutual Insurance Com-



pany and of the Boston Woven Hose and Rubber Company. In addition, because of a deep interest in education, he has served for many years as a member of the Corporation of the Massachusetts Institute of Technology and as a trustee of Northeastern University and of Norwich University.

During the second World War, he was chief of the Guided Missile Division of the National Defense Research Committee at a time when few had much faith in the future of guided missiles. For his energy and foresight in promoting continued research along these lines, he was awarded the Presidential Medal for Merit and later was Chairman of the National Academy of Science Ordnance Advisory Committee on Guided Missiles.

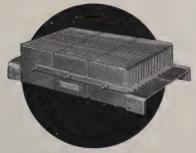
# Holtum New CE for Andrew Calif.

A. G. Holtum, Jr. was recently appointed to the position of Chief Engineer with the Andrew California Corp., Clare-

(Continued on page 70A)

# SILICON RECTIFIERS

# ... the widest range in the industry!



SELENIUM INDUSTRIAL POWER RECTIFIERS

For all DC power needs from microwatts to kilowatts. Features: long life; compact, light weight and low initial cost. Ratings: to 250 KW, 50 ma to 2,300 amperes and up. 6 volts to 30,000 volts and up. Efficiency to 87%. Power factor to 95%. Bulletin C-349



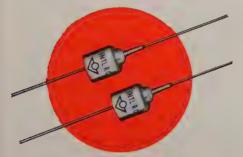
HIGH CURRENT DENSITY SELENIUM RECTIFIERS

A complete line for natural convection cooling in industrial applications. Inverse voltage ratings up to 36 volts per cell, Rectified DC output approximately twice that of standard selenium stacks in approximately 50% less volume. Write for Bulletin SR-152



SELENIUM PHOTOCELLS - SUN BATTERIES

Self-generating photocells available in standard or custom sizes, mounted or unmounted. Optimum load resistance range: 10 to 10,000 ohms. Output from .2 MA to 60 MA in ave. sunlight. Ambient temperature range: -65°C to +100°C. Bulletin PC649



HIGH VOLTAGE SILICON POWER DIODES

Two styles available. Hermetically sealed, pigtail construction. Style J features PIV ratings from 600 to 1000 volts at 125 ma. DC output current. Ask for Bulletin SR-138E Style K: PIV from 600 to 1200 volts at 100 ma DC output current. Bulletin SR-144A



SILICON RECTIFIER STACKS

These units consist of hermetically sealed junction diodes mounted on copper cooling fins, stacked to include the interconnections required for specific circuits. Junction ratings: 1.25 amps. DC output; 70 to 350 AC input volts rms. Request Bulletin SR-137A.



SILICON CARTRIDGE RECTIFIERS

The answer to tough miniaturization problems! Ratings for high temperature applications: from 1000 volts PIV at 100ma half-wave DC output to 16,000 volts PIV at 45ma. Hermetically sealed, metallized ceramic housing. Request Bulletin SR-139B



330 AMP GERMANIUM JUNCTIONS

Low current density germanium junctions of high capacity for heavy duty applications. Corrosion resistant, cast aluminum cooling fins dissipate heat at high rate. Efficiency: 98.5. Six types. Input voltage ratings from 20 to 66 volts rms. Request Bulletin GPR-2



500 AMP GERMANIUM JUNCTIONS

Six high capacity junction types especially suited for extra-heavy duty such as electrochemical installations where air cooling is desirable. Cast aluminum airfoil housings. Input voltage ratings from 20 to 66 volts rms. Efficiency 98.5. Bulletin GPR-2



LIQUID COOLED GERMANIUM JUNCTIONS

Liquid cooled for maximum power in minimum space. Junction rating: 670 amps at 26 to 66 volts rms. Housed in high-conductivity copper cast around special steel coils. Water, oil or other accepted coolants may be used. For complete data. Bulletin GPR-2.

Corporation or contact the International Rectifier branch office or representative nearest you.

# RECTIFIER CORP.

INDUSTRIAL METALLIC RECTIFIERS

CHICAGO AREA OFFICE: 205 W. WACKER DR., PHONE FRANKLIN 2-3888 . NEW ENGLAND AREA OFFICE: 17 DUNSTER ST., CAMBRIDGE, MASS., PHONE UNIVERSITY 4-6520

PROCEEDINGS OF THE IRE October, 1957 69A



Union Digital and Alpha-numerical Indicators are electro-mechanical, D.C.-operated readout devices for displaying characters in accordance with a predetermined code. The character display may be made to suit the users' requirements.

Indicators are designed for plugin mounting in a row so that data or messages of any desired length can be stored, displayed or transmitted at will. The indicators can be applied to the output of digital computers, teletype receiving equipment in conjunction with a buffer storage unit, telemetering systems, or wherever data needs to be displayed.

An important feature of these indicators is their inherent storage and transmitting characteristics, which provide for data entry and retransmission. The indicators can be used to accept data from a source, free the source for other programs, and disseminate the data from one indicator to another as required.

Two interesting applications: The Alpha-numerical indicator is being used in data display equipment for flight control built for CAA wherein data enters the system by keyboard or via teletype at 60 words a minute, or from magnetic drum storage at speeds up to 1000 words per minute.

The Digital Indicator is being used in pipeline remote control systems, for displaying and storing telemeteral data such as temperature, pressure, flow, etc. in a central office. Write for Bulletin No. 1011 for further information.

# UNION SWITCH & SIGNAL DIVISION OF WESTINGHOUSE AIR BRAKE COMPANY

PITTSBURGH 18, PENNSYLVANIA



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 64A)

mont, Calif., an affiliate of Andrew Corporation, designers and manufacturers of antennas, antenna systems, and transmission lines.

Holtum had previously been with the Army Electronic Proving Ground, Ft. Huachuca, Arizona.

This appointment is part of the expansion of Andrew western facilities to permit closer cooperation with customers in devel-



opment of antenna systems for telemetry, airborne communications and similar applications.

#### Power Tetrode Transistor

A new power tetrode transistor, said to be the first of its kind in the electronics industry has been introduced by the Minneapolis-Honeywell Regulator Co., Semiconductor Products Div., 2753 Fourth Ave., S., Minneapolis 8, Minn. It was unveiled at the four-day Western Electronic Show and Convention in San Francisco.



The new transistor is expected to have wide application in the audio field because it faithfully reproduces input signals used in the design of high-fidelity amplifiers; it is said to reduce the amount of circuitry required. In addition, the power tetrode is more easily stabilized than existing transistors where thermal runaway is a problem. The tetrode is designed to operate on a 28-volt system and can carry up to 10 amperes. The company is prepared to take orders for sample quantities of the new power tetrode.

# Nuclear Laboratory Equipment Catalog

In a 28-page booklet giving complete coverage to the selection of nuclear laboratory equipment, Tracerlab, Inc., 1601

(Continued on page 74A)



... if they involve Deposited Carbon Resistors

# DALOHM has the answer!

All Dalohm products are carefully designed and skillfully made to assure you of supreme quality and dependability, plus the widest versatility of application.

Outstanding examples of the Dalohm line are these deposited carbon resistors, made for accurate performance where carbon composition resistors are not suited or wire wound resistors too expensive.

You Can Depend On



TYPE DO

Pure crystalline carbon film bonded on ceramic rods of special material; provide precision resistance values, low voltage coefficient, low capacitive and inductive characteristics in high fre-

• Resistance ranges from 10 ohms to 50 megohms

• Tolerance 1% or higher as specified

quency applications, extremely high

stability and economy.

• Five wattages—1/8, 1/4, 1/2, 1 and 2; eight physical sizes

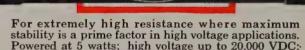
Write for Bulletin R-24A

TYPE DCH

Essentially the same as type DC except hermetically sealed in a non-hydroscopic ceramic envelope to provide absolute protection against thermal shock, salt water immersion and humidity.

Write for Bulletin R-27A

TYPE DC-5



stability is a prime factor in high voltage applications. Powered at 5 watts; high voltage up to 20,000 VDC; resistance range 1 megohm to 200 megohms; tolerance 1% or up to 10% on request.

Write for Bulletin R-28

JUST ASK US You are invited to write for the complete catalog of Dalohm precision resistors, potentiometers and collet-fitting knobs.

If none of our standard line fills your need, our staff of able engineers and skilled craftsmen, equipped with the most modern equipment, is ready to help solve your problem in the realm of development, engineering, design and production.

Just outline your specific situation.

DALE PRODUCTS, Inc.

1302 28th Avenue

Columbus, Nebraska, U.S.A.

• Export Dept: Pan-Mar Corp. 1270 Broadway New York 1, N. Y.

Borg is a highly respected name in its field . . . the manufacture of components for systems. Borg has gained wide recognition as a supplier of electronic components for military and commercial uses.



Borg manufacturing plants are centrally located about 90 miles from Chicago. Easily accessible by highway, rail and air.

# BORG MAKES

Precision Is Our Business. For many years Borg has been prominent in the design and manufacture of precision components for systems.

#### AIRCRAFT INSTRUMENTS

Aircraft components, instruments and electronic sub-assemblies.

#### • FREQUENCY STANDARDS

Crystal controlled oscillator type frequency standards.

#### POTENTIOMETERS

Quantity production of Borg MICROPOTS (precision potentiometers) to meet your specifications.

#### MICRODIALS

Precision MICRODIALS for single and multi-turn devices. Indexed accuracy of up to one part in 1,000.

### INSTRUMENT MOTORS

Precision motors, synchronous and induction types. Gear trains.

# BORG CAN HELP YOU

Borg can assist you in the design and construction of prototypes. Complete facilities for pilot runs and quantity production. Write for Bulletin BED-A50 or call us today.



# BORG EQUIPMENT DIVISION

THE GEORGE W. BORG CORPORATION JANESVILLE, WISCONSIN



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 70A)

Trapelo Rd., Waltham 54, Mass., pictures a complete line of counting, sample preparation, personnel protection and survey, "hot lab" and storage equipment as well as complete reference standards. The booklet features two comprehensive tables one of which gives the efficiency, speed, and other vital information on all detectors listed in the tables. The second table compares the features of the various scalers and shows the accessory equipment with which they may be operated.

Photographs of complete composite units representing the total nuclear instrumentation requirements for typical applications help in the selection and coordination of laboratory equipment.

The booklet may be had by writing for Bulletin SN, to the Technical Publications Dept.

### Miniature C-R Tube



Raytheon Manufacturing Co., 55 Chapel St., Newton 58, Mass. announces an improved version of the 3UP1, a small-sized, all glass,  $1\frac{9}{16} \times 2\frac{1}{8}$  inches rectangular flatfaced cathode ray tube. A new two-piece bulb design permits the flat faceplate to have a uniform thickness which greatly improves this feature over the previously available tubes. Other features of the tube are a phosphor screen size of  $1\frac{1}{8} \times 1\frac{3}{4}$ inches, electrostatic focus and deflection,  $1\frac{9}{16}$  inch neck diameter,  $7\frac{1}{2}$  inch tube length with a standard 12-pin base. For use as a display indicator, the 3UP1 can be made available with various screen colors and persistances.

Further details are available from Technical Information Service.

# L & N Opens Canadian Firm

Organization of Leeds & Northrup, Canada, Ltd., a wholly-owned subsidiary of Leeds & Northrup Co., of Philadelphia, was announced by I. Melville Stein, Chairman of the Board of the new company and President of its parent organization. The firm, located at 61 Industry St., Toronto 15, will manufacture and distribute the electronic controls and measuring instruments formerly supplied from the United States.

President of the new Company is J. William Robinson, formerly of Philadelphia and more recently Coordinator of Western Operations for Leeds & Northrup.

"The basic function of the Company" said Stein "is to give better serv-



J. W. ROBINSON

ice to . . . Canada's expanding economy."

# Delay Generator Brochure

A four page brochure, illustrating and describing the operation of a new Precision Delay Generator, the Type 6010, designed as a piece of laboratory type test equipment for applications which require accurate, variable, time interval pulses, was just published by the Electronic Instruments Div., Burroughs Corp., 1209 Vine St., Philadelphia 7, Pa.

In this brochure, the Precision Delay is divided into its three operating units, the Trigger Generator, Delay Generator and the Regulated Power Supply, and the operation of each unit is described. In addition all output waveforms from the Delay Generator are illustrated along with the particular specifications for each waveform such as rise time, pulse width, amplitude, etc. All other operation specifications, both electrical and physical, are included in the brochure.

Free copies of this brochure are available upon request to Burroughs Corporation, Electronic Instruments Division.

# Reliability Report

Twelve simple guides for the design of reliable electronic equipment are contained in a volume prepared for Navy electronic engineers and technicians and just made available for industry use through the Office of Technical Services, U. S. Department of Commerce.

The report was compiled primarily for guidance in the design of ground based data-gathering and data-assessing equipment, but contains information useful to designers of other types of electronic devices. Most of the data was drawn from an extensive literature survey. An 89-item bibliography is included in the report.

The guides were based on studies of the effects of increased equipment complexity, distribution of causes of equipment failure. technique of reliable design, and selection of components. Such tube-reliability factors as filament current surges, cathodeinterface formation, tube envelope temperatures, new cathode designs, and the use of special tubes also were considered.

The report, PB 121123 Twelve Guides to Reliable Electronic Design, G. G. Johnson, U. S. Naval Ordnance Laboratory, Apr. 1955, may be ordered from OTS, U. S. Department of Commerce, Washington 25. It contains 57 pages, price \$1.50.

(Continued on page 76A)

Shock after Shock

THROUGH THE SONIC BARRIER...

BORG MICROPOTS
Can take it!

# MEM!

# BORG 910 SINGLE-TURN PRECISION MICROPOT

WRITE FOR
CATALOG SHEET BED A-69
AND NAME OF YOUR
NEAREST BORG TECH-REP

# BORG EQUIPMENT DIVISION

THE GEORGE W. BORG CORPORATION

JANESVILLE, WISCONSIN





#### TRANSISTOR TRANSFORMERS

Encapsulated miniatures developed out of Triad's long experience with precision design and high quality workmanship. A partial listing of our available types is shown on the right. For complete specifications, including Hermetically Sealed types, write for Catalog TR-57.

ĺ	Type No.	Primary Impedance	Secondary impedance	Maximum Level	
ı	TY-64X	32 CT. (575 Ma.)	16/8/4	10W	233
ı	TY-65Z	32 CT. (575 Ma.)	6000/4000/3000	10W	
Į	TY-48X	100 CT. (40 Ma.)	8/4	500MW	
	TY-58X	125 CT. (15 Ma.)	8/4	200MW	
	TY-57X	250 CT. (10 Ma.)	16/8/4	200MW	П
	TY-27XT	500 CT. (2 Ma.)	500 CT.	10DBM	н
	TY-28XT	500 CT. (2 Ma.)	200 CT.	10DBM	ı
	TY-45X	500 CT. (5 Ma.)	16/8/4	200MW	ı
	TY-55X	2000 CT. (2 Ma.)	500 CT.	200MW	L
	TY-59X	5000 CT. (1 Ma.)	50000 CT.	200MW	Ł
	TY-56X	10000 (1 Ma.)	2000 CT.	200MW	ı
	TY-54X	15000 (1.5 Ma.)	200 CT.	200MW	
	TY-52X	20000 CT. (1 Ma.)	2000 CT.	200MW	
	TY-50X	125000	2000 CT.	200MW	
20					



(Reduced Inspection Quality Assurance Plan) Your own incoming inspection and field service requirements are reduced to a minimum when you specify Triad. All Triad Transformers are manufactured under this Signal Corps approved plan for quality assurance. The system includes approved procedures for incoming inspection of material, in-plant process controls, preliminary and patrol inspection, and final inspection in the plant. Transformers passed are approved for shipment for military use.

4055 REDWOOD AVENUE, VENICE, CALIFORNIA 812 E. STATE STREET, HUNTINGTON, INDIANA

A SUBSIDIARY OF LITTON INDUSTRIES



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 74A)

# Computer Multiplier

A wide band, all-electronic analog computer multiplier designed for high accuracy and speed is announced by **Chadwick-Helmuth Co.**, 472 E. Duarte Rd., Monrovia, Cal.



The unit generates a voltage proportional to the instantaneous product of two arbitrary input voltages from dc to 5 kc, with less than 5  $\mu$ sec delay. Accuracy is  $\pm 0.1$  per cent of full scale over most of the band. After a short warmup, no adjustments are required for at least eight hours if accuracies of  $\pm 0.25$  per cent are adequate. Built-in metering system facilitates calibration and performance testing while unit is in use.

The instrument operates with a 450 kc carrier, which is phase-modulated and amplitude modulated by the two inputs to produce an output proportional to the product of these two modulating voltages. Modulation and demodulation is performed in diode-ring balanced modulators of special design to yield the required linearity, stability, and trouble-free operation.

Designated Model 251, the unit is now in production. Literature will be sent on request.

# Regulated Voltage and Current Supply

A new regulated voltage and current supply in a single unit, designed specifically for transistor engineering has been announced by **Oregon Electronics**, 2105 S. E. Sixth Avenue, Portland 14, Ore.



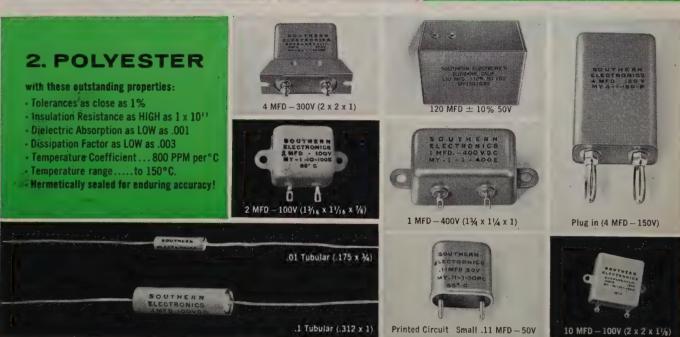
The model CV-10-10 will deliver regulated voltage or current in the ranges 0-3; 0-10; 0-30; and 0-100 volts or milliamperes. By setting the limiter control, the output power will be automatically interrupted before safe limits are exceeded.

(Continued on page 80A)

# where precision counts-it's S.E.C. first!

# PLASTIC PRECISION CAPACITORS







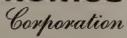
# 3. RC NETWORKS

- Close tolerances
- Hi-grade precision resistors
- Potted units
- Meet mil specs

Many other types of precision RC Networks available!

S.E.C. PRODUCTS HAVE BEEN SPECIFIED IN SEVERAL MISSILE APPLICATIONS!

# SOUTHERN





For your most exacting requirements —always specify S.E.C.

150 W. Cypress Ave., Burbank, California

PIONEERS IN CUSTOM PRECISION CAPACITOR ENGINEERING

The Donner a-c\*, a complete linear computer. Digital voltmeters, scopes, and non-linear equipment may be mounted above the console and/or at one side in modular racks.



\$16,650

buys the new DMMER a-c\* console

#### WITH

- 30 Chopper Stabilized Amplifiers
  - 40 Coefficient Potentiometers
  - 0.1% Temperature Controlled Computing Components
    - Latching Overload Lights

Designed as a standard production item, the Donner a-c\* combines quality and flexibility with modest cost. For instance, characteristics of the Donner 3101 chopper stabilized operational amplifier, heart of any analog computer, are: dc gain  $5\times10^7$ ; unity integrator drift 100 microvolts in 15 minutes; phase shift  $0.2^\circ$  at 1000 cps. The reference supply carries a stability of  $\pm$  0.1% over a 60 day interval.

Formed from molded diallyl phthalate, the removable AMP problem board serves 30 amplifiers, 40 potentiometers, complementary nonlinear equipment, and 70 trunk lines.

Starting with as few as 10 amplifiers and 20 potentiometers, the user can build up a full console as his needs and pocket-book dictate. For further expansion, consoles may be slaved together and operated from one master computer.

Data file 310 detailing the Donner a-c\* is yours for the asking. Please address Dept. 4410





These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 76A)

An audible or visual alarm can also be used.

When the power supply is used as a regulated voltage supply, the system becomes a current limiting circuit, and when set up as a regulated current supply it becomes a voltage limiting device.

Ripple, when voltage regulated, is less than 2 millivolts peak to peak. When current regulated, ripple is less than 2 millivolts peak to peak across 100 ohm load.

Complete details and specifications may be obtained by writing the manufacturer.

# Ruge Appoints Ochlis Sales Manager

Arthur C. Ruge Associates, Inc., Cambridge, Mass., developers and manufacturers of temperature transducers and systems, announces the appointment of Samuel Ochlis as Sales Manager.

Ochlis formerly was Sales Promotion and Advertising Manager for Electronics and Instrumentation Division of Baldwin-Lima-Hamilton, and was Sales Manager for Ruge-De-Forest Company when it merged with Baldwin-Lima-Hamilton.



Ochlis attended Northeastern University's School of Mechanical Engineering. He served in the U. S. Army Air Corps during World War II, and is a member of the Instrument Society of America, Society of Experimental Stress Analysis and National Industrial Advertisers Association.

#### **Resistors Bulletin**

Two technical bulletins concerning voltage-sensitive resistors and negative temperature coefficient resistors have recently been released by the Globar Div., The Carborundum Co., Niagara Falls, N. Y.

Bulletin GR-2 deals with the physical and electrical characteristics of Type BNR Varistors—voltage-sensitive resistors. Bulletin GR-3 covers the physical and electrical characteristics of Types B, F and H Thermistors—negative temperature coefficient resistors.

Both bulletins contain charts, tables and conversion curves relative to applications of Varistors and Thermistors. The bulletins are available on request from the firm.

(Continued on page 82A)

# ODULIZE

# SERVO SYSTEMS

### QUICKLY INTERCHANGEABLE ... EASILY SERVICED

Miniaturized

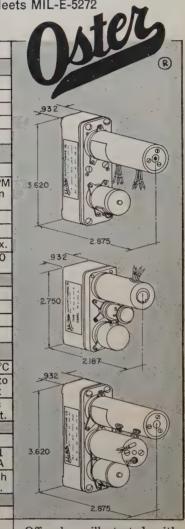
Lightweight

• Simple, fast installation

Meets MIL-E-5272

• Can be hermetically sealed with dimensional changes

OSTER TYPE	SB-9805-01	SB-9805-02	SB-9805-03	SB-9805-11	
Motor	. , .	1.00		· ·	
Fixed Phase Voltage	26v	115v	115v	26v	
Control Phase Voltage	26v	115v	115v	26v	
Frequency	400	400	400	400	
Max. Power @ Stall	6	5	5	6	
No Load Speed ·	10,500	10,000	10,000	10,500	
Generator					
Excitation Voltage Phase 1	26v			26v	
Output Phase 2	0.3v/1000 RPM 100,000 ohm load			0.3v/1000 RPM 100,000 ohm Ioad	
Null .	.012v			.012v	
Wobble Voltage	.007v			.007v	
(Power Excitation)	3.5 watts Max.			3.5 watts Max.	
Linearity	0.5% to 4000 RPM			0.5% to 4000 RPM	
Potentiometer					
Mechanical Rotation	360°	360°	360°	360°	4
Resistance	1000 ohms	50,000 ohms	50,000 ohms	1000 ohms	
Accuracy of Total Resistance	±5%	±5%	±5%	±5%	
Electrical Angle	350° -	350°	350°	350°	~
Servo Block Unit					`
Ambient Temperature	-55°C to 72°C	-55°C to 72°C	-55°C to 72°C	-55°C to 72°C	
Altitude	-1000 feet to 55,000 feet	-1000 feet to 55,000 feet	-1000 feet to 55,000 feet	-1000 feet to 55,000 feet	
Life	3000 hours excluding pot.	3000 hours excluding pot.	3000 hours excluding pot.	3000 hours excluding pot.	2 :
Gear Train					
Ratio	1000:1	336:1	167:1	10,000:1	
Dust Enclosed per	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A	
Backlash	Anti-Backlash gear on pot.	1°	1°	Anti-Backlash gear on pot.	. ,
Synchro					
Input Voltage—Stator	11.8v				
Output Voltage—Rotor	10.6v				
Clutch Brake					
Input Voltage		100v dc	100v dc		
Input Power		2.0 watts Max.	2.0 watts Max.		
Operate Time—Energize		5 milliseconds	5 milliseconds		
Operate Time—De-energize		20 milliseconds	20 milliseconds		



Offered as illustrated with identical or different combinations of:

gear ratios clutch brake clutch-brake

servo synchro motor-tach potentiometer

Write for further information TODAY, enclosing details of your requirement.

Other products include motorgear-trains, synchros, AC drive motors, DC motors, servo mechanism assemblies, motor tachs, servo torque units, reference and tachometer generators, actuators, motor driven blower and fan assemblies and fast response resolvers.

John Oster

# MANUFACTURING COMPANY

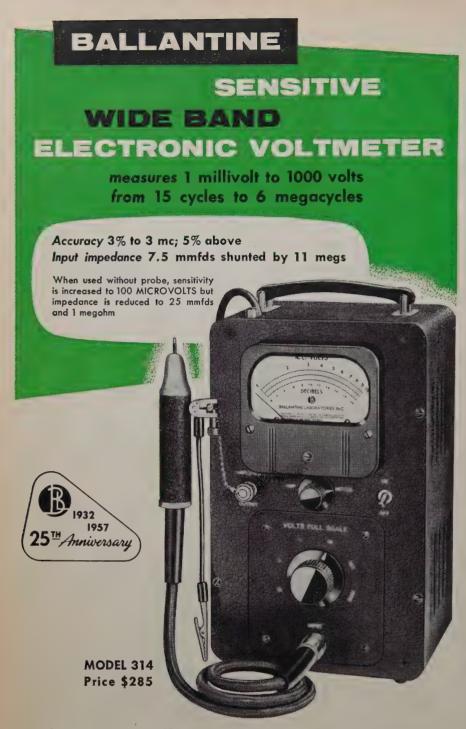
Your Rotating Equipment Specialist

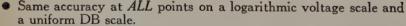
**Avionic Division** 

Racine, Wisconsin

Engineers For Advanced Projects:

Interesting, varied work on designing transistor circuits and servo mechanisms. Contact Mr. Zelazo, Director of Research, in confidence.





- Only ONE voltage scale to read with decade range switching.
- No "turnover" discrepancy on unsymmetrical waves.
- Easy-to-use probe with self-holding connector tip and unique supporting clamp.
- Low impedance ground return provided by supporting clamp.
- Stabilized by generous use of negative feedback.
- Can be used as 60 DB high fidelity video pre-amplifier.

All Ballantine instruments are SENSITIVE - ACCURATE - DEPENDABLE

Write for catalog for complete information.

# BALLANTINE LABORATORIES, INC.



102 Fanny Road, Boonton, New Jersey



(Continued from page 80A)

# Spectrum Analyzer

The Edin Company, Inc., 207 Main St., Worcester 8, Mass., announces a new spectrum analyzer which analyzes any complex electrical waveform continuously within its frequency range and presents a readout showing the frequencies included in the waveform and the amplitudes of each of the frequency components. Waveforms may be continuous or discontinuous. The analysis is performed over successive 10-second periods. Other periods available on special order. The readout is a Bar Graph produced by a pen writing galvanometer showing a frequency spectrum.



Each band consists of plug-in electronic band-pass filters. The frequency and band width should be specified in each request.

The stability of the instrument is such that long-term stability is better than 2 per cent. Filter and integrator circuits are set at factory, and require no readjustment. The only controls requiring setting are those on the amplifier which set the incoming voltage gain, and the pen excursion and selector switches on the amplifier of the spectrum analyzer which establishes the mode of operation.

By means of switches, any of the following types of analysis may be obtained:
(a) Integrated volt-seconds per epic period for each of the component frequency bands. (b) Peak voltage of each of the component frequencies per epic interval (c) Average voltage continuously occurring in any one of the bands. (d) Peak voltage reading continuously in any one of the bands. Standard model covers 24 bands by selection of plug-in filters.

Frequencies available from 0.5 to 20,000 cps. Other frequency ranges are available on special order. Basic standard unit: \$4500.00.

(Continued on page 88A)





RELIABILITY



ECONOMY



VERSATILITY





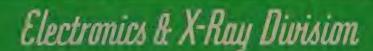
Whether meter or millimeter measurements are contemplated, no microwave laboratory is complete without the FXR 'Z815B' Universal Klystron Power Supply. Unsurpassed for proven dependability and versatility, this supply incorporates the many qualities that have made FXR craftsmanship and 'know how' ... the standard in the industry,

Price \$1360 Loli Weenside, N. Y

### **FXR TYPE Z8I5B-SPECIFICATIONS**

		OUT	UT:			MODUL	ATION		
TYPE	VOLTAGE (volts)	CURRENT (milliamperes)	INTERNAL IMPEDENCE (ohms)	ADDITIONAL SPECIFICATIONS	TYPE	FREQUENCY RANGE	NOMINAL VOLTAGE (volts)	RISE Till (microseco	FALL NE nds, max.)
Beam	200 to 2000 1800 to 3600	250 W to 3600V 0 to 10 000 cms Resolution		Voltage Dial Accuracy: ± 1% Resolution: 0.5 volts Regulation: 0.03% from	Square Wave	250 to 2500	0 to 200	1.0	1.0
Reflector	Defined and Market		105 to 125 volts Ripple: 3 mv rms, max.	Pulsed Wave	I to 10 microseconds pulse width	0 to 200	1.0	1.0	
Control Grid	Positive 0 to 5 Ontrol Grid 0 to 150 Negative 0 to 300		0 to 30,000	Regulation: 0.03% from 105 to 125 volts Ripple: 3 mv rms, max.	Sine Wave	line frequency	0 to 200		
Filament	6.3	3 amperes		Unregulated	Saw Tooth Wave	40 to 120	0 to 200	Variable	30
DIMENSIONS (inches)	Width: 213 Height: 153 Depth: 18		HV Line: Fuse, 4	lable overload relay 25, 65, & 12	25 ma PO1	VER 105 to 125 v	olts, 50-60 cp	s, 300 to 800	) watts

Data subject to change without notice



FR MACHINE WORKS, INC.

26-12 Borough Place, Woodside 77, New York

Write Today...

for your new catalog of
Precision Microwave
Test Equipment.

# Perma-Power

SPECIFICATIONS

Output Current: 0-15 MA and 0-60 MA

Accuracy: 2% on both voltage and current

Ripple: Less than 500 microvolts (.002%

Regulation: 1.2 Volts Maximum; Zero to

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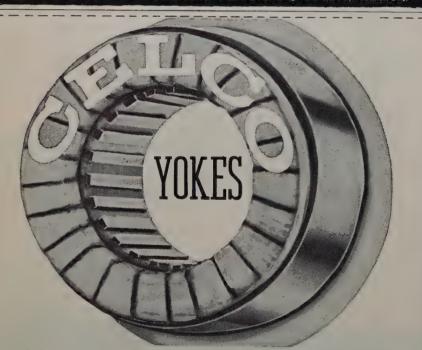
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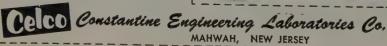
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These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 82A)

# Dynograph Recorder

A new Dynograph Direct Writing Oscillograph Recorder, the Type 503, is now in production at Offner Electronics Inc., 5320 North Kedzie Ave., Chicago 25, Ill. The new unit, a mobile console assembly, is designed for applications requiring more than 8 channels of information on one recording chart. Up to 19 recording channels are available in the Type 503 Dynograph, using either ink or electric curvilinear recording. The manufacturer supplies 24½ inch printed paper, either in roll or folded form, and 500 foot unprinted rolls as desired



Pen spacing of 2 inches is normally provided with assemblies of 12 channels or less, and pen spacing of 11 inches with assemblies of 13 through 19 channels. Other pen spacing can be supplied if desired. The paper is driven by a synchronous motor and eight speed gear box, providing instant selection of speeds of 1, 2.5 5, 10, 25, 50, 100, and 250 mm/sec., accurate to 1 per cent. Paper is driven from both edges.

Complete details and specifications are available by writing Offner.

#### CTS Moves Eastern Office

To provide better customer servicing. Chicago Telephone Supply Corp., Elkhart, Ind., variable resistor manufacturer, has moved its Eastern sales office to 5 Haddon Ave., Haddonfield, N. J., according to Henry Sanders, sales manager. New local phone is Haddonfield 9-5512 and new teletype Haddonfield 529. The Market 7-3129 Philadelphia phone remains unchanged. The office was first established over 30 years ago to provide on-the-spot technical service as well as the usual sales service to CTS customers in the eastern seaboard area from Boston to Baltimore. Remaining in charge of customer servicing is Huey L. Slough.

(Continued on page 104A)

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THE COVER-The release of hundreds of kilowatt hours of electrical energy in a single stroke of lightning is a major source of noise in radio communications systems. Although the physics of this discharge is simple in concept, its detailed description is so complex that even today the processes by which lightning is generated are not fully understood. An excellent review of the presently available facts and most recent authoritative conclusions concerning this phenomenon is presented in the article on page 1331.

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# Scanning the Issue-

The Electrification of Precipitation and Thunderstorms (Gunn, p. 1331)—Despite the fact that lightning is one of nature's most commonplace spectacles, the mechanisms by which it is produced has remained one of the major puzzles of science. It is evident that a predominance of electrical charges of a like sign builds up in a rain cloud until the electric field intensity exceeds the dielectric strength of the atmosphere. At this moment, it is estimated, the cloud potential exceeds 100 million volts and the lightning discharge that follows will probably expend 500 killowatt hours of energy. But by what processes is this enormous store of electrical energy accumulated? The importance of static in radio communications and an avid curiosity about its origin prompted the PROCEEDINGS editors to find out. They turned to one of the world's leading authorities for an explanation of the basic physical processes involved. The result is a paper which all readers will find rewarding and stimulating. Despite the complexity of the subject, the author unravels in a clear fashion much of the mystery surrounding this awesome phenomenon. Starting with the generation of ion pairs in the atmosphere by cosmic rays and other mechanisms, the reader is taken through the steps by which rain drops become selectively electrified and a final gross separation of positive and negative charges occurs. The discussion discloses new facts as well as reviewing old ones in what is probably the most complete and authoritative explanation of the generation of atmospheric electricity that has yet been published.

An Improved High-Gain Panel Light Amplifier (Kazan, p. 1358)—The panel light amplifier is a relatively new device which has many interesting potential uses. In essence, it consists of a layer of photoconductive material (cadmium sulfide powder) followed by a layer of electroluminescent phosphor, with an ac voltage applied across the two layers. In the dark the high impedance of the CdS layer permits only a negligible fraction of the ac voltage to be applied across the phosphor layer. When light falls on the CdS, its resistance decreases and a greater exciting voltage appears across the phosphor layer, resulting in the emission of light at a greater intensity than the input light falling on the CdS layer. This paper reports on some substantial improvements that have been made since the first experimental model was announced two years ago. These improvements have to do with the method of connecting the individual photoconductive elements in the panel to the rest of the circuit so as to enable a more efficient type of operation, and the development of a more sensitive CdS powder. The result is a much improved light amplifier whose gain is 10 times greater than any previous amplifier and whose threshold for input light is greatly reduced. The high gains and long persistence of the device make it potentially useful in intensifying the low-light-level images that are common to slow-scan TV and certain radar screens. Moreover, the device is sensitive to infrared and, especially, X-ray radiation. In the latter case the light amplifier can convert an X-ray image into a visible picture 100 times brighter than a fluoroscope screen which, until now, has been the primary means of direct viewing of X-rays.

The Large-Signal Behavior of Crossed-Field Traveling-Wave Devices (Feinstein and Kino, p. 1364)—This paper considers a class of traveling-wave devices in which the electron beam flow is perpendicular to both the dc electric and magnetic fields. After developing a large-signal theory of operation, the authors employ an analog computer to analyze the operating characteristics of a forward-wave amplifier, backward-wave amplifier and backward-wave oscillator. The results show clearly the relative merits and limitations of these devices with respect to gain and efficiency. This is the first large-signal analysis that has been made of crossed-field tubes,

and as such represents an important, original contribution to the microwave tube field.

A Versatile Multiport Biconical Antenna (Honey and Jones, p. 1374)—A novel antenna system has been developed which can be used as a new type of direction finder or as a multiplexer at microwave frequencies. The antenna itself consists of two flared cones mounted in tandem so that the neck of one points down the mouth of the one behind. The antenna feeds into a coaxial line, each quadrant of which is channelled off into a separate waveguide. The direction of arrival of an incoming signal is given by the relative amplitudes of the signals in the four waveguides. Alternatively, with additional waveguide circuitry the propagation modes in the system can be separated and brought out to three separate ports. The phase difference between two of them again gives the angle of arrival of a received signal. Because the three ports are well isolated from each other, this latter arrangement can be turned around and used as a multiplexing system and omnidirectional transmitting antenna. The novelty and versatility of the system will make it of considerable interest in the fields of antennas, microwave communications and navigational electronics.

Radio Propagation Above 40 MC Over Irregular Terrain (Egli, p. 1383)—Radio transmission above 40 mc usually takes place over terrain which is dotted with trees, buildings and other irregularities so that the standard formulas for calculating propagation attenuation under idealized conditions become unsatisfactory. In this paper the author analyzes a large number of propagation measurements, made in the past by various organizations, in an effort to derive empirically relations for terrain effects versus frequency, antenna height, polarization and distance. His results, presented in the form of nomographs and correction curves, will be very useful to those dealing with the service area of vhf and uhf broadcasting stations and mobile communication systems covering distances up to 40 miles. In particular, this study will find direct application to problems of systems design, frequency allocation, and interference evaluation.

Design Theory for Depletion Layer Transistors (Gärtner, p. 1392)—The continuing effort to increase the operating frequencies of transistors is aimed primarily at two problems: increasing the speed with which carriers travel from the emitter to the collector junction, and reducing the values of the internal RC combinations in the transistor. Because very high electric fields may be created in the depletion layer of a reverse-biased p-n junction, it has been proposed that injecting carriers into this region would result in maximum attainable carrier speeds, thus meeting the first problem. At the same time, careful design would, it is felt, keep the RC values low enough to insure operation up to microwave frequencies. This paper takes a theoretical excursion into the design of this new type of transistor, presenting valuable information on the behavior of one form of the device and suggesting other forms and modes of operation for future study.

A Note on Numerical Transform Calculus (Boxer, p. 1401) —Over the past ten years several numerical transform techniques have been developed for solving integro-differential equations of a type that arise in problems involving linear and nonlinear systems. These techniques have proved valuable in analyzing the behavior of networks and in using digital computers in the solution of problems. This paper modifies and extends previous methods by overcoming the difficulty of including the initial conditions in the working of the problem and by increasing the accuracy of the solution.

# Poles and Zeros



Questions. Two issues ago, in announcing the recent formation of the Professional Group on Education, we expressed the hope that this group would quickly uncover problems peculiar to education in electronics and the allied arts. Now, from another source, comes a proposal that would appear to be proper grist for the PGE mill.

Writing in a recent issue of *Harper's Magazine* ("Can We Grow Geniuses in Science?," June, 1957), Lancelot Law Whyte asks in effect: How can outstanding students of science and engineering be inspired to original thinking, to the synthesis of new and embracing concepts? How can they be turned away from preoccupation with mere elaboration or refinement of past art?

Mr. Whyte's answer\* is: "Ask the right question.... It is a commonplace that fertile scientific activity results from posing of the right questions. But they must not only be posed, the attention of the young must be called to them as a deliberate policy.... We cannot produce genius at will, but if it is there we can provoke it. We cannot say whether America will produce an Einstein tomorrow, but we can at least plant flags in the unknown." Whyte proposes that faculties concerned with scientific education should proclaim each year "ten unsolved fundamental problems lying in the broad field of the faculties ... and let these problems be collected in a master Book of Problems, lying open to all on the reference desk of every scientific library."

Why, indeed, should not the PGE Administrative Committee set up as one of its immediate objectives the compilation of an IRE Book of Problems and give it wide circulation among students and teachers in science and engineering? The other Professional Groups could act as expert advisers in choosing the questions and phrasing them incisively, to stimulate rather than to baffle. Some questions would be of the fundamental type proposed by Mr. Whyte; others might relate to more immediate concerns, such as improvements in the design and application of devices and components.

Examples readily come to mind. In the fundamental realm, the PG on Information Theory has been wrestling in the pages of its *Transactions* with the conceptual difficulties associated with the word entropy. Originally devised for thermodynamics, this term has been adopted

by students of information theory because there is an engaging similarity between the disorder of a thermodynamical system and the disorder of an information transmission system. But the analogy is by no means exact, and use of one word to cover the two situations may in fact generate more confusion than understanding. An IRE Problem posed to bring out the subtle distinctions in the disorder states of communication systems, versus other disorderly disciplines, might well be on the list.

As a second example, closer to home, the PG on Electron Devices might well draw attention to the wide gulf separating our understanding of semiconductors as used in the cathodes of vacuum tubes, as contrasted with their use as the base material in transistors. The former is still cook-book artistry after 40 years; the latter has become almost an exact science in a decade. What insight, what controls and measurements are needed to take oxide cathodes out of the kitchen? As a third example, if we want to uncover a second Einstein, the PG on Antennas and Propagation might wish to pose the problem of the propagation velocity of the field of gravity, its detection and measurement.

Participation. The educational matters discussed above are just as much the concern of the non-educational members of IRE as they are of the professors. In fact, one of our most prominent educators has been heard to observe that, if you leave such matters to the likes of him without industry drive behind them, not much concrete progress can be expected. So the constitution of the PG on Education wisely provides that half the membership of the Administrative Committee shall be from the teaching profession and half from industry. Practicing engineers and scientists in industry who have ideas to offer or axes to grind in the educational sphere are therefore urged to join this group and to make themseives available to assist in its management. Write HO for the application blank; the assessment is \$3.00 per year.

Reminder. We hope to close the books on the IRE Editorial Survey at the end of next month. So, if you have not participated in the survey, consult the PROCEEDINGS for June 1957, pages 737 and 884. Then write your Section Chairman.—D.G.F.

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Frank A. Polkinghorn

DIRECTOR, 1957-1958

Frank A. Polkinghorn was born in Massachusetts and received his education in California, graduating from the University of California (Berkeley) in 1922 with honors in electrical engineering and membership in Eta Kappa Nu, Tau Beta Pi, Sigma Xi and Phi Beta Kappa.

From 1922 to 1924 he was employed in the Radio Laboratory of the Mare Island Navy Yard. In 1924 he became Chief Engineer of the A-P Radio Laboratories, successors to the Moorhead Laboratories, one of the early manufacturers of vacuum tubes. In 1925 he entered the employ of the Pacific Telephone & Telegraph Co. in San Francisco as a transmission engineer, transferring to the Radio Research Department of the Bell Telephone Laboratories in 1927.

From 1928 to 1948 he had a prominent part in the establishment of the high frequency transoceanic radiotelephone circuits of the A. T. & T.
Co., including pioneer work in the use of single sideband operation. He was also active in the early applications of frequencies above this range to point-to-point applications. During World War II he did work on the Loran system, various radar systems, and bombsight and communication projects.

From 1948 to 1950 he was on loan to the Army in Japan, where he was Director of the Research

and Development Division, Civil Communications Section, Supreme Command for Allied Powers, in which position he had supervision of all communications research, development, and manufacturing in Japan. In appreciation for this work he was elected an Honorary Member of Denki Tsushin Gakkai, the Japanese counterpart of the IRE.

He served on several receiver committees in the 1930's; his participation on the High Frequency Receiver Committee resulted in the IRE standardization in 1932 of the use of resistance noise for the rating of radio receivers. He was a member of the Admissions Committee from 1941 to 1948 and was largely responsible for the writing of the Admissions Manual. He has also served on the Sections and National Convention Committees and is presently a member of the Policy Advisory Committee. He held various offices in the Northern New Jersey Subsection and became the first full-term Chairman of the Northern New Jersey Section in 1954.

He is a member of the AIEE, AAAS, Montclair Society of Engineers, Armed Forces Communication & Electronics Association and is a licensed professional engineer of the State of New York. In addition, he rose from IRE Associate in 1925 to Fellow in 1938.

# The Electrification of Precipitation and Thunderstorms\*

ROSS GUNN†, FELLOW, IRE

The following paper is one of a planned series of invited papers, in which men of recognized standing will review recent developments in, and the present status of, various fields in which noteworthy progress has been made.—The Editor

Summary-The fundamental physical processes responsible for the observed electrification of ordinary precipitating clouds, as well as thunderstorms, is considered in quantitative terms and new facts are emphasized. Cosmic rays and radioactivity, sometimes supplemented by corona and photoionization, produce ion pairs in the atmosphere. These ions are transferred to cloud droplets or ice crystals by diffusion or by electric fields and thereby establish a droplet charge distribution. This distribution is profoundly influenced by the observed differences between the positive and negative light ion conductivities in the atmosphere. Electrification by induction frequently supplements these processes. Rain formed by the association of these cloud elements may be highly electrified and a mixture of positive and negative drops is usually produced. Experimentally wellestablished processes are considered that can selectively charge such rain or selectively discharge it. It is shown that either process can establish a free space charge distribution that is transferred toward the ground by gravity, and may be large enough to develop electric fields exceeding the dielectric strength of air. Lightning then intervenes. The conditions necessary to establish gross free charge distributions by regeneration are specified and shown to be met under frequently occurring meteorological situations. Many of the observed characteristics of thunderstorms are traceable to the nonuniform semiconducting nature of the lower atmosphere and its nonohmic behavior. The analysis reflects the results of earlier work.

#### Introduction

THE instantaneous release of some hundreds of kilowatt hours of electrical energy by a lightning discharge is one of nature's most awesome spectacles. Although the lightning discharge has excited the wonder of many men, the complexities of weather processes have obscured the fundamental electromechanics and delayed the collection of data necessary to illuminate the basic physical processes. Urgently required data on the distribution of free electric charge within a thundercloud are still missing, although flights through some 25 active thunderstorms by the highly instrumented laboratory aircraft of the Army-Navy Precipitation Static Project [11] have provided a number of highly valuable samples. These samples may not represent all the thunderstorms distributed over the world and in too many cases the measurements are contradictory. This writer is sensitive to the fact that the observations are still incomplete and not always consistent or accurate, but our critics may notice that flying in active thunderstorms is somewhat hazardous and that our small store of data was obtained only

\* Original manuscript received by the IRE, May 17, 1957.

† U. S. Weather Bureau, Washington, D.C.

after the highly instrumented project airplanes had been intentionally flown through some 25 active thunderstorms and been struck by lightning three times! The author, accordingly, bequeaths to an unsympathetic critic the job of collecting many more facts. We trust that he will be lucky.

The object of the present review is to bring together the presently available and reliable physical data on thunderstorms and attempt to synthesize from them as complete a quantitative description of the electrified thundercloud as these data permit. The principal problem of thunderstorm electricity is to describe those processes responsible for establishing the over-all free charge distribution just before lightning is initiated. The physics of the actual discharge is simple in concept, but its detailed description is complex. A discussion of its characteristics, therefore, are reserved for separate analysis.

The electrostatic state established inside a thundercloud by meteorological processes can usually be represented by a steady state. Accordingly, if one had a complete space-wide description of the electrostatic potential, electric field, or free space charge at any given instant, he could immediately calculate most of the required physical quantities. Actually, such data are far beyond the reach of present measurement techniques and one must be content with samples of the above quantities and use these as a framework to support a consistent quantitative description. In general, the potential differences cannot be measured and our knowledge of the electrostatic state is based primarily upon electric field measurements, and the charges carried toward the ground on the precipitation particles inside active thunderstorms. Valuable clues to the basic processes can be inferred from the measured charges deposited on the earth by rain.

An improved understanding of the fundamental processes has resulted from the invention and development of new instruments for measuring the electrical state and the important physical characteristics of falling rain. The development of adequate instruments has absorbed much of the writer's effort but their description will be found elsewhere [14, 15, 21, 42]. It is sufficient to notice that out of the instrument development program has emerged electric field meters capable of

operating continuously in very heavy rain both on the ground and on aircraft. These instruments measure continuously both the sign and magnitude of the electric field and have a response time of about one second. Such data are of the utmost importance in assessing thunderstorm electrification processes.

Supplementing the above have been instruments which permit the determination of the sign and magnitude of the free charge carried on falling rain. It is sometimes possible to measure simultaneously the mass of the drop by means of an instrument which has been particularly valuable on aircraft in providing specific information on the drop charges and their approximate distribution. Other devices, such as a small wind tunnel employing ionized air as the moving fluid, have been of great value in the laboratory. Descriptions of some of the above instruments will be found in the Bibliography [14, 15, 21, 42].

As a direct result of efforts to develop new and better instruments, we have the largest store of coherent measurements yet made in the field of atmospheric electricity; their availability is reflected in the conclusions and references cited herein. The emphasis in the present review has been largely determined by these measured data. Theoretical estimates have been invoked primarily to bridge some of the present gaps in the measurements and to guide the interpretation.

The common active thunderstorm is a veritable museum of atmospheric phenomena. Clouds, heavy rain, snow, and hail are commonly produced and intermixed in a typical active storm and the whole matrix is bathed in turbulence and vertical air currents of great complexity. It is inevitable, therefore, that the electrical phenomena will be extremely difficult to interpret and describe in quantitative terms. Thunderstorms commonly develop in thermally disturbed air masses during the summer months or whenever large amounts of water vapor are present in the atmosphere. The typical summer thunderstorm is approximately 20 kilometers in diameter, although the cloud mass itself may be somewhat more extensive. It commonly extends vertically about 12 km but occasionally may develop to 15 km with an increased probability for the production of hail. The complexity of typical thunderstorms suggests that many processes contribute to the observed state [1, 10, 47] and therefore, it is particularly necessary to separate those that are most energetic for quantitative discussion. These selections will doubtless lead to differences of opinion but as long as one clings steadfastly to the observed data, these differences need not be serious.

# CHARACTERISTICS OF ACTIVE THUNDERSTORMS AS OBSERVED ON THE GROUND

As far as this writer is aware, normal lightning activity has never been observed in clear air except in the vicinity of falling precipitation. There is much additional evidence showing that the principal electrical effects accompanying a thunderstorm are closely related to the

production and fall of precipitation. Precipitation is necessary but is not always sufficient to induce visible electrical activity. The free electrical charges brought to the earth by rain may vary over a wide range; it has been observed that electrical activity may be produced even with moderate precipitation. Conversely, heavy precipitation like that frequently encountered in a mature hurricane sometimes develops surprisingly little lightning activity. The connection between precipitation and lightning activity, therefore, is not a direct one.

# The Electrification and Energetics

The electrification observed in thunderstorms implies the gross separation of free electrical charge with a consequent expenditure of large amounts of energy. It is important to understand this process. The electrification is usually established by a three-stage mechanism whereby positive and negative ions are first generated from neutral molecules by cosmic rays and radioactivity, or in special cases by corona or photoelectric effects. The ions are transferred to cloud droplets by diffusion and conduction. The cloud droplets, in turn, unite to form a mixture of positively and negatively electrified raindrops. The rain is then selectively electrified to permit a final gross separation of positive and negative charge. Under special conditions, charge is separated by the more efficient processes of induction.

Cosmic rays produce about 10 ion pairs per cubic centimeter per second in the lower atmosphere and this increases, more or less uniformly, to 45 at an altitude of about 14 km. Extensive measurements show that when cloud droplets are present, the ions produced by cosmic rays normally diffuse onto the cloud droplets to establish an equilibrium charge. For a typical cloud containing 400 droplets per cubic centimeter, all having a radius of 6 microns, it is found that the droplets in every cubic kilometer of cloud normally accumulate a total charge of the order of one coulomb. Cosmic rays will separate this much charge in about five minutes. The above clouds are nearly neutral and half of the droplets carry positive charges while the other half carry negative charges. These two first stages of thunderstorm electrification are perfectly clear and capable of quantitative formulation. However, when the cloud droplets grow into raindrops and these fall in the atmosphere in the presence of electric fields, the electrical processes become enormously complex. Many data are available describing the probable subsequent course of events and these will be considered in later sections.

The energy necessary to separate the free charges carried by the raindrops is derived from gravitational forces and it is necessary to show that they are adequate. The electric field throughout a typical thunderstorm is frequently observed to be about 150 volt/cm or 0.5 statvolt/cm, although fields 20 times this are known to occur [12]. The energy density required to establish the field is  $(\frac{1}{8}\pi)E^2$  erg/cm³ so that at a given instant the total electrostatic energy W of the storm is

$$W = \frac{1}{8\pi} \int E^2 dU = 10^{-2} U = 2 \times 10^{16} \text{ erg}$$
  
= 550 kilowatt hours, (1)

where dU is the element of volume U. In a typical storm this volume approaches  $2 \times 10^{18}$  cm³. Perhaps most of this calculated energy is expended in a single lightning stroke whose energy is specified by the product of the effective potential and the transferred quantity of electricity. Therefore, because we will show presently that a typical stroke neutralizes some 17 coulombs, one may estimate that the initial cloud potential exceeds  $10^8$  volts. It is not surprising, therefore, that lightning sparks 5 to 10 km long are frequently produced in the free atmosphere.

Consider a precipitating thundercloud in which the liquid or crystalline water content (LWC) is a representative 10-6gm/cm<sup>3</sup>. The work that the free water in this unit volume can do in falling towards the ground a distance h is (LWC) gh. where g is the acceleration due to gravity. This energy must necessarily exceed the electrostatic energy stored in the same unit volume or  $(1/8\pi)E^2$ . Thus, if E approximates 0.5 statvolt/cm the electrostatic energy may be derived from the available condensed water falling a distance of only 10 cm. Since raindrops normally fall many kilometers, the available gravitational energy is thousands of times more than that necessary to establish a typical electric field. Therefore, fairly inefficient electrical processes are entirely capable of describing a common thunderstorm. It is worthy of note in passing that the free water transferred to the high levels in the atmosphere ultimately derives its energy from the sun which originally evaporated the water from the earth.

It is clear that the precipitation must always be electrified if active lightning is to be produced. Many suggestions have been made as to the basic electrification processes [4, 10, 22, 24, 36, 47]. Perhaps most processes invoke the transfer of ions to the drops by diffusion, by conduction, or by differential convection. Others, of a more energetic type, such as direct induction or selective conduction induced by polarization, play an important role. Still others attributing the charge to systematically oriented surface layers have their special advocates. Irrespective of the particular process, the charges on raindrops may be greatly enhanced whenever large numbers of electrified droplets associate to form larger raindrops [24, 25, 32].

### Electric Field

Perhaps the most important index of thunderstorm activity is the electric field measured both at the ground and inside the active cloud high above. A vertically upward surface electric field corresponding to a positive surface charge is adopted as positive. This is the definition used by physicists and mathematicians and is opposite in sign to that used by a number of workers in atmospheric electricity. In fair weather the surface

electric field intensity is negative and approximates -1.5 volt/cm. The development of clouds over a given observing station usually has little influence on the fair weather field until 10 or 20 minutes before precipitation is observed at the ground. The electrification of the droplets permits a selective electrification of the cloud as a whole that thereby produces measurable electric fields at the surface. In a typical stable cloud the electric field is less than 10 volt/cm and probably less than 1 volt/cm. When the cloud becomes unstable and produces slight precipitation, the electric field measured on the ground commonly approximates +10 to +25 volt/ cm and may fluctuate or even reverse sign. Frequently this electric field is quite steady and as the precipitation rate or vertical convection within the cloud increases, the electric field may increase to  $\pm 50$  or more volts per centimeter at which time discontinuities in the electric field are sometimes observed [13]. These discontinuities normally accompany a lightning or invisible static discharge. In the presence of sufficient cloud instability and vertical convection, a typical thunderstorm is produced and the electric field at the ground may then increase to about  $\pm 100$  volt/cm with maxima up to ±140 volt/cm. Marked discontinuities in the field are observed at the instant of nearly every lightning discharge and reversals of sign are common. In an active storm the electric field may be either positive or negative but the basic charging processes, once the thunderstorm is well started, are such as to produce predominantly positive electric fields at the earth's surface.

A network of eight electric field meters was installed in Kansas during the thunderstorm season of 1955. We have complete records of the electric field established at these stations by an active thunderstorm throughout a three-hour period just prior to and after a disastrous tornado passed through Udall, Kan. One station within a mile or two of the funnel lost the door of the barn in which it was housed. Excerpts from these records are given in [30] and in Fig. 1. Their analysis shows that, in general, the electric field may be built towards negative electric field values for the first and last 10 to 20-minute period as shown in Fig. 1, part 3. During the main part of the thunderstorm, however, the electric field is positive 61 per cent of the time but builds towards positive electric fields more than 90 per cent of the time as in Fig. 1, part 1, and Fig. 1, part 2. Such a field implies that an excess negative charge systematically accumulates in the clouds overhead. The main problem of thunderstorm electricity is to describe the processes whereby this charge and the associated electric field are produced and show how to calculate their magnitude.

In the above thunderstorm, the measurements show that the electric field *just prior* to the lightning discharge was positive in 88 per cent of some 2600 events. Moreover, the electric field immediately after the discharge was negative in 65 per cent of the cases. This implies, and the records clearly show, that the typical lightning discharge not only neutralizes the free charges accumu-

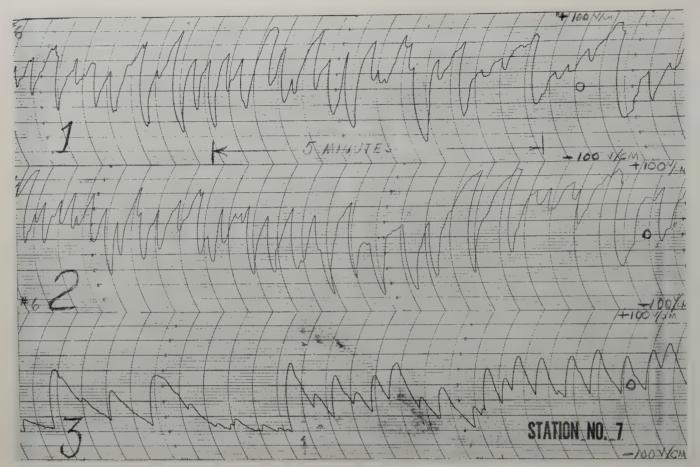


Fig. 1—Extracts from electric field intensity records measured at ground. Active Kansas thunderstorm, May 25, 1955. Electric fields in two top records build toward positive fields. The lower record builds toward negative fields. The measured discontinuities are always accompanied by a lightning discharge.

lated overhead but, in the majority of cases, apparently overneutralizes the charge and develops an electric field which is usually of opposite sign to that existing prior to the lightning stroke. To be more specific, it is found that the average electric field is this active Kansas thunderstorm just prior to a lightning discharge was +41 volt/ cm and after the discharge was -10.4 volt/cm. The number of discharges, wherein negative charge was neutralized overhead, was more than 10 times the number of events when positive charge was neutralized, and the average measured *change* of electric field was -50.2volt/cm or 0.16 statvolt/cm. The largest electric field measured by the writer on the ground was +140 volt/ cm, which we will see is less than 1/10 of the maximum electric fields commonly measured on aircraft well inside an active thundercloud.

The mean charges neutralized by lightning as summarized in the above data may be immediately calculated by noticing that the electric field observing stations were probably only two or three kilometers below the free charge distributions and therefore these may be assumed to approximate a horizontal sheet. Neglecting the fringing near the edges of these clouds one may write that

$$E = 4\pi\sigma = 0.16 \text{ statvolt/cm}$$
 (2)

where E is the observed electric field and  $\sigma$  is the free charge per unit area of the cloud. Now if one considers only the change in the electric field, it is clear that the change in  $\sigma$  corresponds to the discharge of the cloud. Now analysis of many thunderstorms shows that a typical storm has dimensions of  $20~\rm km \times 20~km$  so that by (2) one finds that the average charge neutralized for more than 2600 measurements approximates 17 coulombs. This value is in good agreement with earlier estimates by other investigators.

Further analysis of the same thunderstorm shows that as the thunderstorm increases in intensity the number of lightning strokes per minute steadily increase to an average maximum value of 4.4 strokes per minute. At the particular station closest to the passage of the tornado funnel the lightning rate increased to an average maximum of 7.2 strokes per minute.

The electric fields measured at the top of mountains exhibit generally the same characteristics as the Kansas storm except that the electric fields are commonly much larger. A program of measurements on mountain tops is currently underway and more data will shortly be available. On top of a mountain nearly 6600 feet high, maximum electric fields of more than 1000 volt/cm have been measured.

### Raindrop Charges

Important clues as to the fundamental electrical processes inside an active thunderstorm may be discovered by a careful study of the electrical charges brought to the earth by rain. It was found long ago that quietly falling rain is weakly electrified whereas raindrops falling from active thunderstorms are usually highly charged.

Gschwend [8] observed that the charges brought down on typical thunderstorm raindrops were seldom of a single sign and that a mixture of positive and negative charged drops was characteristic of almost all storms. This fact has been verified many times and has an important bearing on the interpretation of thunderstorm phenomena. Gunn and Devin [19] measured and analvzed the characteristics of some 7000 raindrops that represented a continuous sample of the drops falling to the ground from an active thunderstorm. The distribution of the number of drops in relation to the sign and magnitude of the free charge they carried is given in Fig. 2. This shows clearly that save for a slight preference for small positive charges the distribution is nearly symmetrical and does not appreciably depend upon the sign of the surface electric field. The mixture of positive and negative drops usually observed and the independence of drop charge and the sign of the electric field show that the origin of these charges is to be found in mechanisms taking place far above the earth's surface.

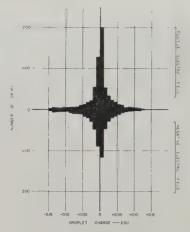


Fig. 2—Number of drops measured at the ground in free charge intervals of 0.01 esu for active thunderstorms of May 5 and June 10, 1950. Total positive charge brought to the ground was 83 per cent of the total negative charge.

Summarizing the data of Fig. 2, it was found that the average charge for positive drops in the above thunderstorm was 0.022 esu/drop and for the negative drops the charge was 0.031 esu/drop. Moreover, the ratio of the sums of all the positive to negative charges brought down on this thunderstorm rain was 0.83. Related sets of data on the charge carried by rain have been given by Scrase [44], by Chalmers and Pasquill [3], and by Banerji and Lele [2]. Average values for raindrop charges are summarized in Table I.

TABLE I

Average Free Electrical Charge on Individual Droplets (ESU×10³)

Observer	Altitude (feet)	Charge	Quiet rain	Shower rain	Electrical storm rain	Quiet snowfall	Squall snowfall
Gschwend (1921)	surface	+	0.24 0.53	1.75 5.43	8.11 5.88	0.09 0.06	5.64 4.78
Banerji and Lele (1932)	surface	+		6.4	6.9 7.3		
Chalmers and Pasquill (1938)	surface	+	2.2 3.0	1.3 2.3	3.7* 9.2*		10.5 5.7
Gunn (1947)	4000 12,000 20,000	+ + + + + + + + + + + + + + + + + + + +		φ 24 41 100 63 φ			
Gunn (1949)	surface	+			15 19	0.67 1.0	
Gunn (1950)	5000 10,000 15,000 20,000	+ + + + + -			81 63 148 112 123 76 52 62		
Gunn and Devin (1953)	surface	+			22 31		

<sup>\*</sup> Actual lightning activity doubtful.

φ No droplets of this sign were observed at the indicated level.

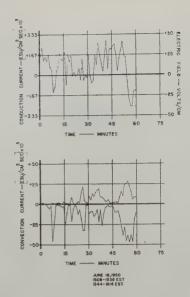


Fig. 3—Top: Electric field and estimated conduction current averaged over one-minute intervals for storm of May 5, 1950 Bottom: The convected current density for positive drops is plotted above the axis. Below the axis is the negative drop current density. The net current density is their sum.

#### Convected Current Density

When the charges on falling rain are directly measured together with their size and numbers per unit volume it is possible to calculate the convected current density *i* through

$$i = \sum NQV$$
 (3)

where N is the number of drops per unit volume, Q is their free charge, and V is their velocity of fall. Since the raindrops all fall towards the ground, the contribution of the positively charged and negatively charged drops are of opposite sign. Accordingly, it is expedient to calculate and plot separately the charge per unit area transferred per unit time to the earth by both the positive and negative drops. Such data [19] are summarized in Fig. 3 and are placed adjacent to simultaneously collected data for the electric field and the presumed conduction current density. The convected current densities for the positive drops are plotted above the axis while those for the negative charges are plotted below. It may be noticed in Fig. 3 that the convected current densities for the positive and negative drops are seldom of the same magnitude and, therefore, rather large fluctuations of the free drop space charge density are generally encountered. These irregularities produce associated fluctuations in the local electric field. Further, since the net convection current density is notably larger than the conduction current of opposite sign, a surplus free charge necessarily accumulates on the ground and this in turn modifies the electric field. One may notice particularly from the observed curve that the excess droplet convected current density is sometimes as much as 4×10<sup>-4</sup> esu/cm<sup>2</sup>sec. These direct measurements permit one to infer, through a simple analysis, that the observed electric fields in the free atmosphere can be excited and maintained by the observed charges on falling rain.

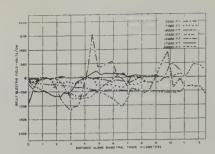


Fig. 4—Electric field intensity measured on belly of B17 airplane during successive passages through active thunderstorm of July 24, 1945 at different levels. Positive fields correspond to positive surface charges at the field meter site.

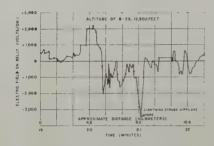


Fig. 5—Electric field intensity at belly of B25 airplane during a lightning strike at 13,000 feet on August 5, 1944.

# ELECTRICAL CHARACTERISTICS MEASURED INSIDE ACTIVE THUNDERCLOUDS BY AIRCRAFT

Although important guide posts for the development of an adequate description of thunderstorm electricity are established by surface data, yet there are many important facts that can be determined only by flying through active thunderstorms. The highly instrumented airplanes of the Army-Navy Precipitation Static Project, which the writer directed during World War II, intentionally flew through some 25 active thunderstorms and succeeded in collecting valuable data. These measurements still provide the best available cross section of thunderstorm electrification phenomena. Many more data are urgently required. The laboratory airplanes were equipped with induction-type electric field meters. both on the top and bottom of the main cabin. A drop charge apparatus was installed under one wing and simultaneous measurements could be made of the electric fields, drop charges, and other more obvious meteorological factors [11, 12, 17].

### Observed Electric Fields

Repeated flights through active thunderstorms showed that the electric field at low levels approaches that commonly measured at the surface and that these fields generally increase to a maximum in the vicinity of the freezing level. Somewhat typical data for a number of passes through the active thunderstorm of July 24, 1945, are summarized in Fig. 4. The measurements show that at altitudes near the freezing level the electric fields frequently exceed a thousand volts per centimeter. In a total of nine thunderstorms examined in 1944 by repeated flights through each, the average measured maximum field was 1300 volt/cm [13]. One flight through an

TABLE II\*

Altitude	Temp.	Positive drops		Negativ	e drops		ace-charge sity	Measured drop	Mean drop mass for liquid water	$(Q/m)_{\rm est}$		
7 Hereade		Number	Charge	Number	Charge	Positive	Negativ <b>e</b>	density	content of 0.5 gm/m <sup>3</sup>	Positive drops	Negative drops	
Feet 5,000 7,500 10,000 12,500 15,000 17,500 20,000	°C +14.7 +10.3 +6.7 +2.4 -0.7 -5.5 -9.9	89 43 71 0 130 45 76	esu/drop +0.081 +0.280 +0.148 	171 47 133 196 150 79 74	esu/drop -0.063 -0.267 -0.112 -0.135 -0.077 -0.041 -0.062	esu/cm³ 5.6×10 <sup>-5</sup> 14.5×10 <sup>-5</sup> 4.9×10 <sup>-6</sup>	esu/cm <sup>3</sup> 3.1×10 <sup>-5</sup> 15.6×10 <sup>-6</sup> 2.9×10 <sup>-5</sup> 7.0×10 <sup>-5</sup> 4.8×10 <sup>-5</sup> 1.6×10 <sup>-5</sup> 3.6×10 <sup>-5</sup>	drop/cm <sup>8</sup> 4.8×10 <sup>-4</sup> 3.2×10 <sup>-4</sup> 2.5×10 <sup>-4</sup> 4.4×10 <sup>-4</sup> 5.7×10 <sup>-4</sup> 4.1×10 <sup>-4</sup> 3.4×10 <sup>-4</sup>	grams 1.0×10 <sup>-3</sup> 1.5×10 <sup>-3</sup> 2.0×10 <sup>-3</sup> 1.1×10 <sup>-3</sup> 0.8×10 <sup>-3</sup> 1.2×10 <sup>-3</sup> 1.4×10 <sup>-3</sup>	esu/gm 81.0 185.0 74.0 — 153.0 30.0 37.0 93.0	esu/gm 63.0 178.0 56.0 123.0 95.0 34.0 44.0	

<sup>\*</sup> Summarized data for drops measured inside active thunderstorm of July 24, 1954. The particle space charge densities are estimated from the drop charges actually observed and, therefore, ignore the smaller and possibly more numerous charges carried by the cloud droplets or very small raindrops. The specific charges, or charges per unit mass, are considered rough.

active storm encountered both positive and negative fields of 2000 volt/cm and a half minute later the field increased to 3400 volt/cm at which time the lightning struck the airplane and damaged some of our instruments [12, 13]. The electric field intensity throughout this interval is shown in Fig. 5. All aircraft electric field measurements are subject to a possible correction of the order of unity because of the unknown orientation of the electric field in relation to that of the aircraft. It is a significant observed fact that 65 per cent of all lightning strikes to operating aircraft occur at outside air temperatures within the narrow range of from 0° to +5°C. Although air traffic at these levels is high, the facts still suggest that the layer of maximum electrical activity can hardly exceed a thickness of 2 or 3 km.

One characteristic of the electric field distribution in thunderstorms is worthy of emphasis. The free charge in the thundercloud is distributed over a large volume and it was originally anticipated that the electric fields would gradually build up as the thundercloud was approached. Actually it was found that the electric field outside the cloud approximated only 150 to 200 volt/cm in the clear air even through the towering cumulus overhead suggested that one was very close to the electrically active centers.

However, just as soon as the aircraft entered the cloud, the electric fields increased rather rapidly and in a matter of 15 seconds the field might increase to  $\pm 1000$  volt/cm. Inside the cloud large values of field, both positive and negative, were commonly encountered, although the geometrical position of the aircraft in relation to the active center of the thundercloud had changed very little [11, 17]. This observed fact emphasizes the importance of space charge layers near the boundary of thunderclouds. The important role of such layers will be discussed in another section.

### Observed Raindrop Electrification

The raindrops inside an active thunderstorm are highly electrified. The writer pointed out long ago that the measured charges were frequently so large that the electric field at the surface of the drop might approach

the dielectric strength of air [14]. This implies that increased charges on the larger drops might initiate corona discharge and thus limit the electrification [14]. The measured electric charges in an active Minnesota thunderstorm are summarized in Table II (above) and show clearly that not only are the electric fields a maximum near the freezing level but the drop charges also. Table II gives not only the measured values of the drop charges. but also a rough estimate of the specific charge or charge per unit mass. A plot of the average free charge carried by the precipitation particles at different positions within the thundercloud at a given level is given in Fig. 6. Many more data of this nature may be found [17]. It is observed that frequently a mixture of positive and negative drops exists but occasionally regions 1 or 2 km in linear dimension contain raindrops of only a single sign [17]. This statement applies only to the measured drops and does not imply that there may not be relatively large numbers of much smaller cloud droplets carrying charges of opposite sign. It is clear. however, that these large rapidly falling drops are primarily responsible for the convective transport of free charge towards the ground by gravitational action and are, indeed, the active agents in separating the free charge within the cloud.

The available data on the electricity transferred to the earth by rain show that the charges are overwhelmingly positive for very light rain and low precipitation rates. But, this decreases with increasing precipitation until in almost all thunderstorms the free charge brought to the ground is predominantly negative [44]. These data probably imply that raindrops become more negative at higher levels and, indeed, this is just what is measured in aircraft flights both in the mild cold front and in thunderstorms which show that at rain-forming levels the total negative charge on the rain is some 60 per cent larger than the total positive charge [12, 17]. This excess may be directly attributed to the differential discharge resulting from the observed differences in the positive and negative light ion conductivities at flight altitudes or to the selective electrification of cloud droplets when  $\lambda_{+} \neq \lambda_{-}$ .

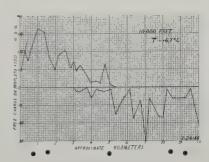


Fig. 6—Measured free charges carried by individual raindrops at various positions inside thunderstorm of July 24, 1945. This curve for 10,000 feet. For additional data, see Gunn [17].

### Comparison of Electrification Inside an Active Thunderstorm with that Observed in a Mild Cold Front

It is of considerable interest to compare the electrical properties of heavy precipitation produced within a mild cold front with those observed inside an active thunderstorm. The laboratory airplane flew through a mild cold front that crossed Minnesota on July 27, 1945. Precipitation was moderate to heavy; no lightning activity was observed. The charges measured on the individual raindrops falling at various levels are summarized in Table III (opposite). A comparison with the thunderstorm data of Table II shows that the measured drop charges on the rain within the cold front were roughly one half of the charge measured on the drops falling within the active thunderstorm. The charges on the raindrops at all levels gave a nearly smooth distribution like that of the solid curve in Fig. 7. This distribution was nearly symmetrical about the axis of zero charge and was roughly Gaussian. On the other hand, the distribution of charges in the thunderstorm suggested great complexity and there were large numbers of drops carrying both positive and negative charges of considerable magnitude, as shown in the dashed curve of Fig. 7. At any given level the data were insufficient to provide representative statistical data, but did show that in both types of storm large volumes sometimes existed wherein the charge on the larger precipitation particles is all of one sign. The data of Tables I and III permit one to estimate the total free charge carried by all the rain drops if they are assumed to be distributed uniformly over a sphere of radius 1 km. One may verify that if the charges are all of one sign, electric fields over the surface of the assumed sphere are great enough to initiate lightning discharges that are not observed. Thus, the summarized data show that charges of opposite sign, presumably on the smaller cloud droplets or the air, are usually intermixed with the charges measured on the large raindrops and that only a partial separation of the measured charges is necessary to establish active lightning. One concludes from a comparison of the thunderstorm and mild cold front regimes that heavily precipitating regions exhibiting modest measured electric fields are intrinsically capable of establishing a

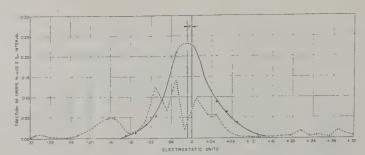


Fig. 7—Distribution of fractional numbers of charged drops in 0.02esu intervals. Solid curve for mild cold front of July 27, 1945. Dashed curve for active thunderstorm of July 24, 1945. The dotted sections imply that weakly charged drops may have been missed.

charge distribution adequate to produce lightning, and that the differences between a mild cold front and a thunderstorm are probably related principally to the selective separation of charges already present on the rain. These seemingly minor differences between the thunderstorm and nonthunderstorm regimes must be objectively considered in formulating a quantitative description of thunderstorm phenomena.

# ELECTRICAL PROPERTIES OF THE SEMICONDUCTING LOWER ATMOSPHERE

The earth's lower atmosphere is essentially a high grade insulator in which ion pairs are continuously formed principally by cosmic rays and radioactivity. Because of the decrease in density of the atmosphere with increasing altitude and because most of the radioactive material is concentrated near the surface, the produced ionization changes markedly with altitude. In addition to the observed variation of ionic density, the ionic mobility regularly increases with altitude, and is somewhat greater for the negative ion than for the positive ion.

The number of ions per unit volume established in the atmosphere at equilibrium depends not only upon the rate of ion production but also upon their rate of disappearance. In clean air the rate of disappearance is determined by the recombination coefficient; but, in ordinary air containing various types of pollution and cloud droplets, the rate of disappearance is determined by a number of factors that have been discussed adequately in earlier communications [22, 23, 31].

The most important factors controlling the electrical state of the atmosphere are the electrical conductivities for the positive and negative light ions and their ratio. By ignoring a number of secondary processes which may be important under special conditions, one may summarize present views regarding the atmospheric conductivity under two headings.

### Clean Air Conductivity

In the absence of suspended particulate matter the rate of recombination of the positive and negative ions is given by

TABLE III\*

Altitude	Temp.	Positiv	ve drops	Negative drops		Particle space of	harge density	Measured	Mean drop mass for liquid water	$(Q/m)_{\rm est}$ .		
Attitude	remp.	Number	Charge	Number	Charge	Positive	Negative	drop density	content of 0.5 gm/m <sup>3</sup>	Positive drops	Negative drops	
Feet 4000 6000 8000 10,000 12,000 14,000 18,000 20,000 22,000 24,000 26,000	°C +12.0 + 8.5 + 6.0 + 3.0 - 1.0 - 4.5 - 7.1 -11.0 -15.5	84 84 8 200 129 80 18	esu/drop	72 59 157 78 130 171 120 12	esu/drop -0.029 -0.027 -0.033 -0.032 -0.100 -0.037 -0.034 -0.032	esu/cm³	esu/cm <sup>3</sup> -0.9×10 <sup>-6</sup> -0.6×10 <sup>-6</sup> -1.3×10 <sup>-6</sup> -1.0×10 <sup>-6</sup> -4.6×10 <sup>-6</sup> -1.5×10 <sup>-6</sup> -1.3×10 <sup>-6</sup> -1.3×10 <sup>-6</sup> -0.1×10 <sup>-6</sup>	drop/cm <sup>3</sup> 2.7×10 <sup>-4</sup> 2.2×10 <sup>-4</sup> 4.4×10 <sup>-4</sup> 2.9×10 <sup>-4</sup> 7.5×10 <sup>-4</sup> 4.1×10 <sup>-4</sup> 3.8×10 <sup>-4</sup> 6.6×10 <sup>-4</sup> 5.1×10 <sup>-4</sup> 3.1×10 <sup>-4</sup> 1.2×10 <sup>-4</sup>	grams 1.8 ×10 <sup>-3</sup> 2.2 ×10 <sup>-3</sup> 1.1 ×10 <sup>-3</sup> 1.7 ×10 <sup>-3</sup> 0.65×10 <sup>-3</sup> 1.2 ×10 <sup>-3</sup> 1.3 ×10 <sup>-3</sup> 0.76×10 <sup>-3</sup> 1.0 ×10 <sup>-3</sup> 1.6 ×10 <sup>-3</sup> 4.2 ×10 <sup>-3</sup> Mean	esu/gm	esu/gm -16 -12 -29 -18 -150 -31 -26 -42 40	

<sup>\*</sup> Summarized data for drops measured inside mild cold front of July 27, 1945. The particle space charge densities are estimated from the drop charges actually observed and therefore ignores the smaller and possibly more numerous charges carried by the cloud droplets or on the small raindrops. The specific charges, or the charges per unit mass are considered rough.

$$-\frac{dn_+}{dt} = \alpha n_+ n_- = -\frac{dn_-}{dt} \tag{4}$$

where n is the number of ions per unit volume and the subscript denotes their sign, e is the elementary ionic charge, and  $\alpha$  is the recombination coefficient. Now if q ion pairs per unit volume per unit time are produced, then the equilibrium electrical conductivities for the positive ions  $\lambda_+$  and for the negative ions  $\lambda_-$  become

$$\lambda_{\pm} = \left[\frac{q}{\alpha}\right]^{1/2} e u_{\pm} \tag{5}$$

where u is the mobility of the appropriate ion and  $\lambda$  is defined by

$$\lambda = \lambda_{+} + \lambda_{-} = \left[ \frac{q}{\alpha} \right]^{1/2} e(u_{+} + u_{-})$$
 (6)

so that the ratio of the conductivities is

$$\frac{\lambda_{+}}{\lambda_{-}} = \frac{u_{+}}{u_{-}} \stackrel{.}{=} 0.8 \tag{7}$$

These expressions are, in general, not applicable near the earth's surface but are somewhat descriptive of the conductivities between 3 and 20 km.

#### Cloudy or Polluted Air Conductivity

Whenever cloud droplets or other suspended nuclei are present in the atmosphere the positive and negative ions not only recombine with each other but are also transferred to the pollution particles or cloud droplets by diffusion. The droplets thereby develop an equilibrium charge which systematically modifies the diffusion of other ions onto the particle and in this way the ionic density of the mobile conducting ions in the air proper is controlled [41]. The rate of combination of positive and negative ions with the suspended particles of mean

population density  $N_0$  and radius a is given approximately by [22]:

$$-\frac{dn_{+}}{dt} = \frac{4\pi a k T u_{+} n_{+} N_{0}}{e \left[ 1 + \frac{Qe}{2akT} + \cdots \right]}$$

$$= \frac{4\pi a k T u_{+} n_{+} N_{0}}{e \left[ 1 + \frac{1}{2} \ln \frac{\lambda_{+}}{\lambda_{-}} + \cdots \right]}$$
(8)

and

$$-\frac{dn_{-}}{dt} = \frac{4\pi akTu_{-}n_{-}N_{0}}{e\left[1 - \frac{Qe}{2akT} + \cdots\right]}$$
$$= \frac{4\pi akTu_{-}n_{-}N_{0}}{e\left[1 - \frac{1}{2}\ln\frac{\lambda_{+}}{\lambda_{-}} + \cdots\right]} \tag{9}$$

where k is the Boltzmann constant, T is the absolute temperature, and Q is the average charge carried by each droplet. When the number of suspended particles per unit volume corresponds to typical clouds the disappearence of ions by diffusion is much larger than by recombination. In this case, one may equate the rate of disappearance to the rate of production and thus calculate the conductivity due to the light ions moving within the cloud droplet space. The conductivity is then nearly the same for positive and negative ions and is much less than in clear air as suggested by (6). Carrying out the substitution it is found for stable clouds that

$$\lambda = \lambda_{+} + \lambda_{-} = n_{+}u_{+}e + n_{-}u_{-}e$$

$$= \frac{qe^{2}}{2\pi a kTN_{0}} \left[ 1 + \frac{1}{6} \left( \frac{Qe}{akT} \right)^{2} + \cdots \right]. \tag{10}$$

Unless  $N_0$  is very large or very small it is necessary to combine the effects of ionic recombination and ion disappearance by diffusion onto the suspended particulate matter. This has been found possible, although awkward, because the ratio of the positive and negative light ion conductivities measures the particulate matter suspended in the air and this ratio can be estimated from  $N_0^2 a^2/q$ , as shown in Fig. 15. Thus by the aid of this curve and expressions in [31], one may estimate the conductivities for any specified atmosphere.

Accordingly it is clear that while the conductivity of the atmosphere is largely determined by the rate of ion production by cosmic rays, radioactivity, and in some cases by corona or photoionization, the cleanliness of the air plays a major role in determining the measured values and their ratio.

### Observed Electrical Conductivity and the Altitude

The electrical conductivity of the lower atmosphere has been measured by many investigators and is known to increase notably with increasing altitude. Gish and Wait [7] have measured the positive and negative light ion conductivities to an altitude of 40,000 feet using aircraft, and found that the positive light ion conductivity was represented by

$$\lambda_{+} = 1.5 \times 10^{-4} [1 + 0.13 \times 10^{-10} Z^{2}] \text{esu.}$$
 (11)

Moreover, the negative conductivity is given by

$$\lambda_{-} = 0.4 \times 10^{-4} [1 + 0.42 \times 10^{-10} Z^{2}] \text{esu}$$
 (12)

where Z is the altitude in centimeters.

Extensive new measurements at this laboratory extending up to altitudes of 20 km, show that the positive and negative conductivities are generally different. At low levels the positive conductivity is normally in excess and at the "crossover point" the conductivities are equal but above this point the negative conductivity is in excess. The "crossover point" according to (11) and (12) is at 7 km, but our measurements show that it frequently is as low as 3 or 4 km, the exact level depending in an important way upon the cleanliness of the lower atmosphere. We have found that the conductivity  $\lambda$  at an altitude Z may be represented by an improved expression of the form  $\lambda = \lambda_0 \exp [fZ - gZ^2]$  where the constants f, g, and  $\lambda_0$  are considerably different for positive and negative ions. The new measurements and the magnitude of the controlling constants will be reported elsewhere by Woessner and Cobb. Their results clearly show that at a level above 3 or 6 km the conductivity due to the negative ions is considerably larger than that due to the positive ions.

The author is persuaded that these observed differences in the conductivities are an important and controlling factor in determining many basic features of the free charge distribution in the atmosphere.

Discharge of Electrified Clouds and Raindrops

Consider any closed surface in the free atmosphere which contains within its boundaries a total free charge Q. If the distribution of the conductivity  $\lambda$  over the surface is known, one may write that the time rate of charge decay is

$$-\frac{dQ}{dt} = \int E\lambda dS \tag{13}$$

where the integration is carried out over the entire surface. Now if  $\lambda$  is nearly constant over the boundary, it may be placed outside of the integral sign so that one may, by the use of Gauss' law, integrate the equation to show that [10]

$$Q = Q_0 \exp\left[-4\pi\lambda t\right] \tag{14}$$

where  $Q_0$  is the initial free charge. This expression is quite general and shows that any free charge is dissipated logarithmically and that it degrades to  $1/\epsilon$  in a time known as the *relaxation time* or

$$\tau = \frac{1}{4\pi\lambda} \,. \tag{15}$$

Since the conductivity of air increases rapidly with altitude, it is evident that the time to discharge clouds at high level is notably less than the time to discharge clouds located nearer the earth's surface. This effect plays an important role in converting double layer distributions of free charge into unipolar distributions much like those frequently observed [10]. Fig. 8 gives a plot of the total conductivity and relaxation times for free charges located at various altitudes in the atmosphere.

It may be noticed from (13) that the rate of discharge depends on the conductivity over the surface where the electric field is measured. Because the atmosphere is, in general, a poor conductor and because the electric fields established in it by thunderclouds are frequently quite large, there is a marked tendency for ions, of a sign opposite to that enclosed by the surface, to accumulate at the surface while ions of the same sign are repelled. Thus, a space charge layer of considerable magnitude may surround the free charge and notably modify the conductivity of the surface region. The rate at which a cloud discharges, therefore, usually depends somewhat on the sign of the charge.

The accumulation of space charge in the semiconducting atmosphere depends both on the electric field and the local conductivity. To emphasize this fact consider the vertical conduction current flowing through a prism extending from the earth to the ionosphere. When a steady state is established, the current density i in the column is a constant. Accordingly,

$$i = \lambda E = \text{constant}$$
 (16)

where E is the vertical electric field intensity and  $\lambda$  is the conductivity. If this expression is differentiated

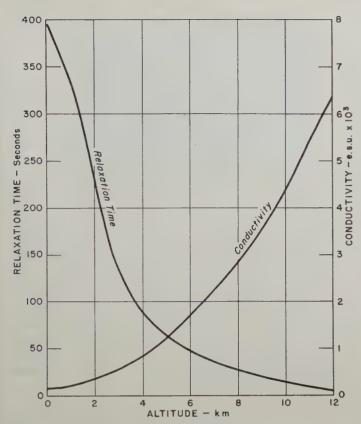


Fig. 8—Estimated electrical conductivity and relaxation time as a function of the altitude.

with respect to the altitude Z, it is found by employing a one dimensional Poisson's equation, that

$$\frac{dE}{dZ} = -\frac{E}{\lambda} \frac{d\lambda}{dZ} = 4\pi\rho. \tag{17}$$

Thus the accumulated free space charge  $\rho$  normally increases with the electric field and decreases as the conductivity becomes large. Substitution of numerical values will show that near the earth's surface space charge effects are likely to be large but at great altitudes they are not so important.

The accumulation of a space charge just outside a highly charged body and its influence on the discharge rate was particularly evident in our experimental work with the laboratory airplane of the Precipitation Static Project. An artificial charging device was invented that could place any selected unipolar charge on the airplane in flight and the current to maintain the charge could be determined as a function of the electric field [11]. We observed very early in our experimental program that the airplane charging characteristics depended on the sign of its free charge. This phenomena is well illustrated by Fig. 9, which shows that the charging current to the airplane is greatest when the airplane is positive and least when it is negative. One may notice further from Fig. 9 that as soon as the belly electric field on the airplane exceeds 300 volt/cm which corresponds to the onset of corona at the wing tips, the discharge regime is

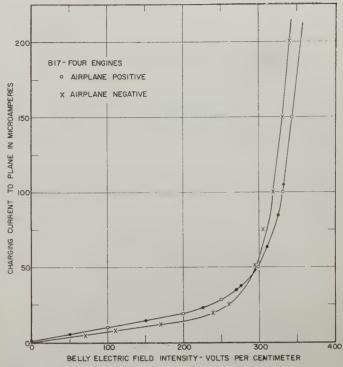


Fig. 9—Unipolar charging currents required to maintain the measured belly electric fields on B17 flying laboratory. Note that more current is required to maintain an assigned positive charge on the airplane than a negative one of the same magnitude. Note that beyond the ohmic region the discharge regime is reversed.

completely reversed. These observed data show very clearly that the conductivity near any surface enclosing a free charge depends on its sign. At the level of highly electrified clouds the conductivity due to the negative ions normally exceeds that due to the positive ions and therefore free positive charge commonly disappears more rapidly than free negative charge. Although such sign selective discharge effects are quite evident in charged raindrops and electrified clouds, it is still improper to conclude from this analysis and Fig. 9 that the relative discharge rates always depend only on the conductivities. Frequently, the discharge circuits extend both to the ground and to the ionosphere and therefore the whole electrical discharge path outside the cloud must then be considered in the over-all determination of the rates.

Highly charged raindrops of both signs commonly are observed in precipitating areas. When the conductivities due to the positive and negative ions are identical, the drops will discharge at the same rate. However, when the conductivities are different as suggested by (11) and (12), the drops of opposite sign are likely to discharge at different rates. This selective discharge process has been shown to develop free space charge distributions in the atmosphere having a considerable magnitude [27]. By using the clear air conductivity values given by (11) and (12) to illustrate the magnitudes, one may calculate how far a raindrop must fall to reduce its charge to any selected fraction of its initial value. Thus, when the

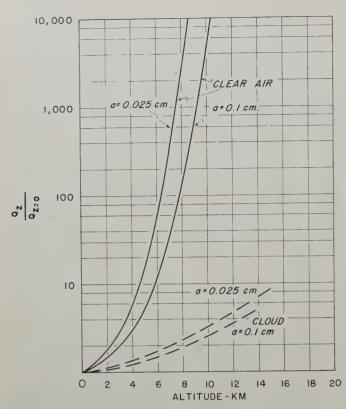


Fig. 10—Ratio of the free charge  $Q_z$  on a raindrop at level Z to its value  $Q_0$  after falling to earth through clear air, and through stable clouds.

electrical conductivities are equal one may plot the solid curve of Fig. 10 showing the charges carried by a drop at altitude Z relative to the charge at the ground after falling through clear air. Because the conductivities inside a cloud are much less, the discharge rates are less and the estimated relative charges may be read from the dashed curve of Fig. 10. Now when the conductivities are different, one must calculate a pair of curves similar to that of Fig. 10 for positively charged and negatively charged drops [27]. The pair of curves so plotted will differ from, but still approximate, Fig. 10.

Although (11) and (12) above suggest that the positive and negative conductivities are equal at the 7-km level, we have data showing that this level sometimes is as low as 3 or 4 km. Accordingly selective charging and discharging will be evident at most rainforming levels and there will be a marked tendency for the positive drops to discharge somewhat faster than the negative drops. Unfortunately, conditions inside a thundercloud are not quite as simple as in the clear air outside and the positive and negative conductivities inside clouds are generally unknown. However, there is accumulating evidence, for example the work of Mathias and Grenet [37], Rossmann [43], Nolan and Nolan [39], and others, all suggesting that the conductivities within a cloud or precipitating regions are much different. The differential discharge of the positive and negative drops would then be very important. The question of selective discharge in thunderstorms can only be finally settled by further measurements. Present data suggest that it plays a vital role in the establishment of free charge distributions.

# Space Charge Layers and Their Effects

It has been emphasized in one of the author's articles that the discontinuity in an electrical conductivity that necessarily occurs at a cloud boundary results in the development of a space charge layer whenever the boundary is traversed by electric fields [29]. The conductivity inside a stable cloud is commonly one tenth that in the clear air just outside. Whenever free charge develops inside a cloud electrical currents flow across the boundary. Continuity requires that the equilibrium current density inside the cloud be the same as it is outside. It then follows that there is a discontinuity in the electric field at the cloud boundary just as shown by aircraft flights into thunderclouds [13, 17]. The layer of discontinuity invariably contains free space charge of a sign opposite to the charge inside the cloud. Further, since the ions produced in the atmosphere recombine or are continually deposited on the cloud droplets, an average free charge density  $\rho$  is commonly established whose magnitude is [29]

$$\rho = \frac{qe}{4\pi} \left[ \frac{1}{\lambda_0} - \frac{1}{\lambda_i} \right] \tag{18}$$

where  $\lambda_0$  and  $\lambda_i$  are the conductivities outside and inside the transition layer. Assuming that the ions in the region are produced principally by cosmic rays (i.e., q=10 ion/cm³sec) one may estimate that the space charge density is the order of  $2\times10^{-5}$  esu/cm³. The thickness of this space charge layer is directly proportional to the electric field, although it does not explicitly appear in (18) [29]. Within a highly electrified thunder-cloud the thickness of the transition layer is both calculated and observed to approximate 1 or 2 km.

The space charges accumulated near cloud boundaries are at first transferred to these regions by ions but if there are cloud droplets or raindrops in this region these ions shortly are deposited on the droplets and the space charge finally resides, for the most part, on the hyperelectrified rain. This special mechanism which communicates systematic charges to the drops approximating  $3E_0a^2$  will be discussed in another section.

The free charges inside a thundercloud always attract ions of opposite sign toward the cloud. This means that space charge established by electrical conduction will always play a secondary but clearly evident role in determining the over-all electric field configuration. For example, the character of the branching from lightning strokes shows rather clearly that free charge opposite to that inside the cloud is commonly present below most thunderclouds. This accumulated free charge is always less than the charge on the main cloud but if the principal cloud charges are suddenly annihilated by lightning, the space charge may still persist. In this event the



Fig. 11—Branching feeder strokes showing partial discharge from low clouds having same sign of charge as that induced on the earth. (Photo courtesy of Albert Ford.)

sign of the resultant charge in the overhead regions is reversed. Reference to the records of Fig. 1 will clearly show this residual charge. The residual charge manifests its presence by an apparent over-neutralization of the charge overhead whenever lightning discharges the main cloud. This space charge accumulated by conduction is discharged by the lightning as evidenced by the brush-like feeders to the main stroke as shown in Fig. 11, but it seems clear from the records that the discharge is commonly incomplete.

### The Layer of Maximum Resistance at Low Levels

Because of the contamination and suspended matter in the lower 3 or 4 km of the atmosphere and its relatively high gaseous density, the conductivity of these lower layers is unusually low. Space charge is then readily developed as suggested by (17) and is frequently large enough to modify the electric fields and currents flowing across the layer. By the use of observed conductivity data one may show that the total resistance offered to the flow of current from the earth to the high atmosphere is located principally in these lower layers. Now if high voltages are developed between the ionosphere and the earth the ensuing currents will be independent of altitude and a large fraction of the potential difference is necessarily found across the lowest layers. The potential differences established between the top and bottom of a thundercloud are frequently in excess of 108 volts. This potential is applied to a closed circuit extending from the top of a cloud to the ionosphere where the charge is distributed more or less uniformly over the earth and the current flows back to the earth in the fair weather regions of the world. The rest of the circuit to the lower parts of the original thundercloud is completed through the conducting earth and through the high resistance layer between the earth and the cloud. Thus, much of the generated cloud potential difference is frequently applied across the low lying layers of high resistance. In this event lightning strokes to the ground may occur and thus, instantaneously transfer charge to the ground. Stated another way, one may notice that the ohmic resistance of these special lower layers is oftentimes so large that nature finds other auxiliary ways to transfer the rapidly accumulating free charge in the clouds to the ground. This process is suggested by Fig. 18.

It is important to notice that the mountainous areas of the earth frequently extend well above the high resistance lower layers and thus effectively provide a low resistance bypass to the high conductivity regions in the atmosphere. Electrification effects and charge transfer in mountainous areas, accordingly, play a larger role proportionately than do the oceanic areas. Eq. (17) suggests and observation shows that space charge phenomena on the tops of mountains play a somewhat lesser role than in low level layers and the distribution of charges is somewhat easier of interpretation. The study of thunderstorm phenomena in mountainous areas is, therefore, unusually important.

#### ELECTRIFICATION OF CLOUD DROPLETS

Since most raindrops are formed by the association of small melted snow crystals or cloud droplets it is important to discover the basic processes responsible for their electrification. During the last few years our laboratory has made tremendous strides in understanding these processes. These electrification mechanisms are of the greatest importance. The diffusion of ions onto the cloud droplets represents a universal process [22, 23, 26]. On the other hand, hyperelectrification and simple induction processes are of controlling importance whenever electric fields are present. Because induction and hyperelectrification [29] both depend on the presence of appreciable electric fields, they play a minor role in describing the initial phases of thundercloud electricity but may become all important after the electric field is once fully established by other electrifying mechanisms.

Laboratory clouds produced in the Weather Bureau's giant expansion chamber have provided much valuable information as to the nature of cloud electrification. The experiments show that when the cloud droplets are first formed by condensation they are all essentially neutral [46]. However, as the cloud ages, atmospheric ions diffuse onto the droplets and after an hour or so it is found that the average droplet carries about 10 elementary ions, half of the droplets being positively charged and the others negatively charged [46]. In order to establish the nature of the electrifying process studies were made of a number of different aerosols dispersed in the air by different methods [28, 46]. For example, cloud droplets formed by sudden expansion from moist air are initially neutral. A sulphur aerosol formed by the condensation of sulphur vapor is similarly neutral. On the other hand, a finely divided cloud of silica particles blown into the air by an air blast are found to be highly electrified both positively and negatively [46]. Water droplets atomized by an air blast are also highly electrified. In spite of the complexities suggested by the above differences in initial behavior of newly formed dust and water clouds, we have discovered that for droplets of the same size the electric charge magnitude and distribution are

TABLE IV\*

Num- ber of									Nun	iber o	f Unit	Char	ges $\bar{q}$								
Colli- sions	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10
0 1 2 3 4 5 6 7 8 9	0.9	1.9	3.9	7.8 17.5	15.6 31.2 43.9	31.2 54.6 70.3	62.5 93.7 109.0 117.0	125 156 164 164	250 250 234 218 205	500 375 312 273 246	1000 500 375 312 273 246	500 375 312 273 246	250 250 234 218 205	125 156 164 164	62.5 93.7 109.0 117.0	31.2 54.6 70.3	15.6 31.2 43.9	7.8 17.5	3.9	1.9	0.9

<sup>\*</sup> Beginning with 1000 neutral drops, the table gives the probable number of drops carrying the assigned numbers of unit charges indicated in the top horizontal line, after suffering the number of unit charge transferring collisions shown in the left-hand column. Note that the distribution after a number of collisions is nearly Gaussian.

finally exactly the same no matter how the cloud is first produced provided the aerosol is aged by exposure to copious ionization [46]. This ionization may be produced by cosmic rays, X rays, or any other suitable ionizer. Since the final equilibrium charge distribution of an aerosol is the same irrespective of the original neutral or highly electrified condition and since the equilibrium depends on the presence of ionization, it is clear that the atmospheric ions are responsible for their charges. The time required to establish the charge equilibrium on cloud droplets is comparable to the value given in (15). But it may be noticed that the potential of the typical cloud particle does not finally approach zero as suggested by (14) but rather a value something less than kT/e. Thus each cloud droplet in the semiconducting atmosphere acts as though it were a tiny electrical concentration cell [10].

The electrification of cloud droplets by diffusion plays an important role in the mechanics of precipitation. When the cloud droplets are electrified like those in Figs. 14 and 16 the establishment of electric fields throughout the cloud may profoundly modify the collision processes and the resulting stability. For example, we have shown that when the electric field exceeds about 2 statvolt/cm the electrical forces may sometimes be as effective as gravity in promoting precipitation [24]. Thus, in the presence of high fields the rate of precipitation may be greatly increased. Indeed, there is evidence to suggest that this process is responsible for the so-called "rain gush" sometimes observed in thunderstorms.

# The Diffusion Charging of Droplets in an Ionized Atmosphere

It has been found possible to show from the ordinary classical diffusion equations that the bombardment of droplets by ions describing free paths as a result of their thermal kinetic energy, act to establish a Gaussian-like distribution of positive and negative drops just like that observed. The fundamental mechanisms may be understood by reference to Table IV. Suppose that cloud droplets are suspended in the air where there are

 $n_{\perp}$  positive ions and  $n_{\perp}$  negative ions per unit volume, and suppose further that their mobilities are  $u_+$  and  $u_$ respectively. Because of the thermal motions of the ions, the ratio of the probability of a positive ion striking a droplet as compared to the probability of a strike by a negative ion is  $n_+u_+/n_-u_-$ . For illustration, suppose that the probability of a droplet acquiring a positive ion is exactly the same as the probability of it capturing a negative ion. Now, if there are a thousand droplets initially, after one ionic collision, 500 droplets will acquire a positive ion and 500 will pick up a negative one. When these electrified droplets capture a second ion, half of the droplets in each new group will acquire a positive ionic charge and the other half a negative charge. Thus, after two collisions 250 droplets will have two negative charges, 500 will be neutral, and 250 will have two positive charges. By carrying out this procedure for each succeeding collision one may show as in Table IV that a distribution is established in which equal numbers of positive and negative cloud droplets are present and the Gaussian-like distribution will be symmetrical about the axis of zero charge. It is especially important to notice from Table IV that the mean charge on the cloud droplets is many times the charge on the parent ions.

It frequently happens that the number of positive and negative ions or their mobilities are different, and this modifies the relative probability of collision. One may easily construct another table in which the probabilities of collision for the positive and negative ions are different [32]. The reader may verify that a distribution is established here also, but the maximum is displaced systematically towards the sign of the droplet charge having the highest probability of collisions.

It should be emphasized here that Table IV describes only the initial phases of the electrification and one may show that as the number of collisions increases to large values, sufficient charge is transferred to the mean drop to reduce the probability of collision with ions of the same sign and increase the probability of collision with ions of the opposite sign. Under such conditions an equilibrium charge is established. This conclusion is

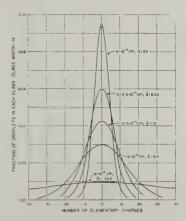


Fig. 12—Distribution of the fractional number of cloud droplets carrying assigned numbers of elementary charges and having different radii. The mean charge,  $\bar{q}$ , irrespective of sign, is indicated on each curve. Distribution calculated from (19) with  $\lambda_+/\lambda_-=1$ .

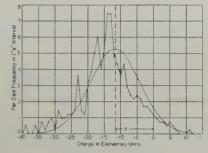


Fig. 13—Measured fractional number of water droplets carrying assigned numbers of elementary charges. Average radius 3.3μ. Measured conductivity ratio λ<sub>+</sub>/λ<sub>-</sub>=0.82 so that average free charge is -11.7 elementary units. Smooth curve is calculated from (19).

based on a careful analysis of the dynamical equilibrium established by diffusion as recently worked out by the author [22, 23]. It is sufficient to mention here that by applying well-established laws describing the motion of particles subject to electric fields and diffusion, one may work out the rate at which ions are transferred and accumulated on a spherical droplet. From these relations it is possible to determine the resulting distribution through a theorem on detailed balancing at equilibrium [23]. In an assemblage of a large number of droplets of common radius a immersed in an environment wherein the ratio of the positive and negative light ion conductivities is  $\lambda_+/\lambda_-$  we have shown that

$$\frac{F_x}{F_t} = \frac{e}{(2\pi akT)^{1/2}} \exp\left[\frac{-\left(x - \frac{akT}{e^2} \ln \frac{\lambda_+}{\lambda_-}\right)^2}{\frac{2akT}{e^2}}\right]$$
(19)

where  $F_x$  is the number of droplets carrying x elementary charges of magnitude e,  $F_t$  is the total number of droplets, k is the Boltzmann constant, T is the absolute temperature, and e is the elementary electronic charge. This is the fundamental electrification equation for aerosols [23], and includes both the statistical and system-

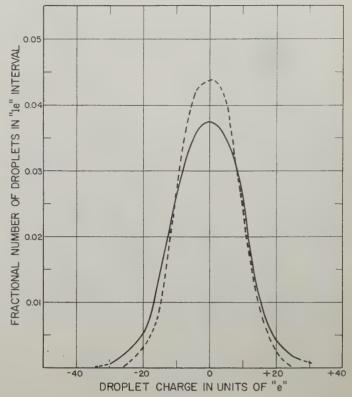


Fig. 14—Observed droplet charge distribution in natural cloud. Radius=4μ. Electric field small. Dotted curve calculated from (19).

atic charging. The distribution calculated from (19) for a number of different droplet sizes is shown in Fig. 12 when  $\lambda_+/\lambda_-=1$ . By integration of (19) one may determine an average number of elementary charges, irrespective of sign, carried by the aerosol particles. From this it is found that [23]:

$$\frac{\bar{q}^2}{2a} = \frac{\pi}{4} kT \tag{20}$$

where  $\bar{q}$  is a previously defined mean charge, averaged without respect to sign [23]. Now since a is essentially the electrical capacity of the droplet, the terms on the left-hand side represent the stored electrical energy, while kT is the probable thermal kinetic energy. Thus an equipartition is established between the electrical and thermal energies of the droplets when equilibrium is finally reached.

The fundamental electrification expression of (19) has been well tested in the laboratory. It may be noticed particularly that when the ratio of the probabilities for capture of positive and negative ions or  $\lambda_+/\lambda_-$  is different from unity, then the curves in Fig. 12 are systematically displaced [28]. An experimental measurement of the distribution under carefully controlled conditions with  $\lambda_+ \neq \lambda_-$  is shown in Fig. 13. The measurements are fully consistent with the basic equation.

For the purpose of comparison with the analysis just indicated, one shows in Fig. 14 the distribution ob-

served in a *natural cloud* on the top of Clingman's Peak, N. C. This cloud was relatively stable and the electric field at the point of measurement was negligible. Thus, in accordance with (19), the distribution would be expected to correspond to  $\lambda_+=\lambda_-$  and be symmetrical about the zero charge axis.

#### Systematic Electrification by Ionic Diffusion $\lambda_{+} \neq \lambda_{-}$

Droplets maintained in an environment wherein the electrical conductivities for the positive and negative ions are different all develop a systematic electrification of preferred sign. This phenomenon is illustrated in Fig. 13. When the cloud particles are sufficiently small the distribution coincides with (19) above, but whenever there is appreciable relative motion between the droplet and its ionized environment this motion modifies the ionic density gradient around the droplet and increases the systematic charge. It may be shown that under these circumstances the falling droplet acquires a mean systematic charge [22] given by

$$Q = \left[1 + F \frac{aVe}{2\pi kTu_{+}}\right]^{1/2} \frac{akT}{e} \ln \frac{n_{+}u_{+}}{n_{-}u_{-}}$$
 (21)

where F is a numerical constant of the order of unity, V is the velocity of fall of the droplet,  $u_{\pm}$  is the mobility of the mean ion in the transition layer next to the droplet, and  $n_{+}u_{+}/n_{-}u_{-}=\lambda_{+}/\lambda_{-}$ . The enhanced electrification due to the motion of the droplet is by no means negligible, because large raindrops falling in a field free region can easily accumulate 20 times the charge that would be developed were the drop maintained at rest. The essential correctness of (21) has been verified by laboratory measurements employing a small wind tunnel supplied with ionized air [42].

It is clear from (19) and (21) that no systematic charge is transferred to the droplets whenever the positive and negative light ion conductivities are equal. According to an earlier investigation this conductivity ratio depends notably upon the number of particles suspended in the air and their radius [31]. The relationship is specified in Fig. 15. Thus, in a typical stable cloud where  $N_0^2 a^2/q$  is large the droplet charges are distributed at random and no systematic electrification is produced. However, in those special regions where there are relatively few droplets or snow flakes per unit volume the conductivity ratio may be much different from unity and considerable systematic electrification produced. (See Fig. 13.) Recent work has shown that rain is initiated in typical warm clouds when parcels of nearly nuclei free air are lifted near the tops of clouds [33]. The droplets then formed by direct condensation are abnormally large and examination shows that the conditions for their production are just those required systematically to electrify them. In the presence of sufficient cooling these droplets may grow to produce raindrops carrying charges of moderate size. Such systematic droplet electrification plays a part in the initiation

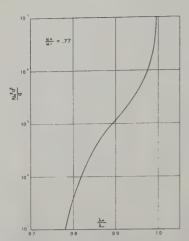


Fig. 15—Calculated relation between  $N_0^2 a^2/q$  and the ratio of the light ion conductivities  $\lambda_+/\lambda_-$ .

of electric fields. Since the process can electrify either snow flakes or droplets it is clear that even warm clouds may develop lightning [6, 24, 25].

#### Hyperelectrification of Cloud Droplets in an Electric Field

Many suggestions have been made as to ways that cloud and raindrops might acquire their charge [36, 47]. Space does not permit a general discussion of this interesting problem and one considers here only those electrification processes that are thought to be so energetic that they probably control the basic phenomena. As emphasized above, ionic diffusion is a universal phenomenon and it is, therefore, particularly important whenever electric fields are not present. However, it is well known that electric fields are commonly generated by precipitation and in their presence very energetic droplet electrification is produced by other processes.

Consider a slightly conducting sphere immersed in an electric field. It becomes polarized and free charges of opposite sign are induced on the opposite polar surfaces. When this polarized sphere is maintained in a conducting atmosphere, the positive ions migrate to the negatively charged areas and the negative ions migrate toward the positive. A careful analysis of this process shows that if the conductivities of the positive and negative ions are equal the sphere accumulates no net charge. On the other hand if the conductivities are notably different the sphere acquires a free charge comparable to the charge induced near its poles or  $\pm 3E_0a^2$  [29]. This process might not be particularly important were it not for the fact that atmospheric electric fields invariably sweep ions of a single sign into extensive space charge or transition layers that mark gross discontinuities in the electrical conductivity. In such transition layers the conductivity ratios may be very large and all the droplets maintained in this region become highly electrified and all have the same sign. On the other hand, a cloud composed of several parts, each separated by clear air, will produce drops of opposite signs on the adjacent faces of the juxtaposed sections. A mixture of charges may then be anticipated. The magnitude and reality of this process which we have called *hyperelectrification* has been established in the laboratory [29]. The magnitude of the charge transferred to such polarized spheres is [29]

$$Q = 3E_0 a^2 \left[ \frac{(\lambda_+/\lambda_-)^{1/2} - 1}{(\lambda_+/\lambda_-)^{1/2} + 1} \right]. \tag{22}$$

The specific charge is therefore

$$\frac{Q}{M} = \frac{9E_0}{4\pi ad} \left[ \frac{(\lambda_+/\lambda_-)^{1/2} - 1}{(\lambda_+/\lambda_-)^{1/2} + 1} \right]$$
(23)

where d is the bulk density of the drops. As an example of hyperelectrification consider Fig. 16 representing the charge distribution on natural cloud droplets observed on top of Clingman's Peak when the cloud droplets were exposed to measured electric fields. It may be noticed that all of the droplets are highly electrified and carry only a negative charge. The observed distribution may be related to variations in droplet size but their mean value is indicated in the caption of the figure. The new data of Figs. 14 and 16 were kindly made available through Dr. Gilbert D. Kinzer.

## Electrification by Induction of Colliding but Nonassociating Snow Flakes and Raindrops $E \neq 0$

Some of the following sections emphasize the enhanced electrification that may be transferred to falling rain as a result of the association of large numbers of electrified cloud droplets. There is, however, a special case of considerable importance wherein electrical effects are produced because the particles do not associate or because they breakup in an electric field. Ice crystals and individual snow flakes are commonly formed at high levels where the temperature is below freezing and these grow to appreciable size by direct condensation of the water vapor. These snow flakes fall at different velocities and frequently collide but thereafter may immediately separate because no surface tension forces promote association as in water droplets. Whenever an electric field is present the snow flakes are polarized and on contact may exchange charge. It is clear that if the colliding particle are favorably oriented with respect to the electric field their separation may produce a highly charged positive and negative pair. In a somewhat similar way raindrops that collide and immediately separate instead of associating will have opposite charges on the separated drops. It is well known that raindrops having a radius greater than about 0.25 cm, commonly break up. Large charges of opposite sign will then be produced by induction on the resulting smaller drops.

Recently Müller-Hillebrand [38] has revived the well-known Elster and Geitel [5] mechanism by showing that ice crystals in collision with graupel possess sufficient conductivity to permit an exchange of charge and thus become systematically electrified. The Müller-Hille-

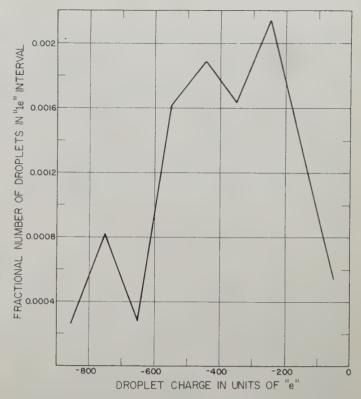


Fig. 16—Droplet charge distribution observed in natural cloud. Radius  $8\mu$ . Electric field  $\neq$  0. An example of hyperelectrification.

brand processes may very well contribute to the electrification but the simple induction processes are much more energetic.

Consider a large number of snow flakes falling in the cold high atmosphere. These flakes are of different sizes and have different aerodynamic properties so that there is relative motion between all the particles and collisions are moderately frequent. Suppose that any two flakes or any two nonassociating raindrops may be thought of as two similar polarized slightly conducting spheres. Now if they collide in such a way that the line joining their centers is in the direction of the electric field, then one may show that the free charge induced on each sphere has a magnitude given by

$$Q = \frac{\pi^2}{3} E_0 a^2 \tag{24}$$

where  $E_0$  is the impressed electric field and a is the radius of the spheres. Upon separation one sphere will carry a positive charge and the other a negative charge of the same magnitude. When the orientation is random, the average charge will be some appreciable fraction of (24). Because the separating components are of opposite sign they will attract each other and in some cases the initial relative kinetic energy between the particles will be insufficient to separate them. Accordingly, the induction process will be important only when the relative kinetic energy is greater than  $Q^2/2a$ . It can be shown that such a requirement is met in most cases and perhaps most snow or ice crystal collisions and

nonassociating raindrop collisions result in oppositely charged *pairs* of magnitude comparable to (24). Such simple induction processes have a marked advantage over other mechanisms because the charging is instantaneous and does not depend either on the generation or on the capture of ions. The mechanism is believed to be of considerable importance. From (24) it follows that the charge per unit mass or the specific charge irrespective of the sign is  $Q/M = \pi E_0/4ad$ .

Electrification by induction is highly efficient and energetic so that when this process is common, a mixture of snow flakes or raindrops carrying nearly equal positive and negative charges will be found in the atmosphere. Because the charges transferred to each particle are proportional to the electric field, flakes falling near the freezing level where the field is normally large are likely to be highly electrified and if they further associate to form rain after they melt, extraordinary high drop charges may be anticipated. The Graupel forming stage, therefore, is likely to transfer excessively large free charges to the drops. Indeed, calculations suggest that corona will be discharged from a small percentage of them [32].

Attention is drawn to the fact that the free water necessary to produce a snow flake is only about 1/50 that for a spherical water drop of the same size [34]. Since the charge induced on each separating flake is proportional to the square of its linear dimensions, it is clear that snow crystals electrified by induction in an appreciable electric field may produce relatively large free charges per unit mass. In the next section we will consider the electrical effects produced when such highly electrified snow flakes melt to form droplets and these further associate to produce enhanced electrification.

### ENHANCED ELECTRIFICATION BY THE ASSOCIATION OF ELECTRIFIED DROPLETS TO FORM RAIN

Enhanced electrification is always produced whenever electrified cloud or rain droplets collide and associate to form rain [24, 25, 32]. Analysis shows that if the cloud droplets are all of one sign the association simply concentrates these free charges on the raindrops and the free charge is conserved. On the other hand, if the parent cloud droplets are composed of a mixture of positive and negative charges the association processes neutralize some of the available free charge. However, the statistics of the processes are such as to establish a mixture that effectively preserves an appreciable fraction. (See Table IV.) This charge is distributed more or less equally among a large number of drops each of which may sometimes carry thousands of the original cloud droplet charges [24, 25, 32].

According to the results of earlier sections a typical cloud consists of large numbers of droplets in which about half of the droplets carry a positive charge that is typically 11 elementary units while the other half typically carries 11 negative units. Normally 4 per cent or less of the droplets are uncharged. Suppose that a small

raindrop falls down through such a cloud and grows by association thus consolidating the charges carried by the cloud droplets. The falling raindrop is accordingly bombarded in a purely random manner by the cloud droplets which it successively intercepts. If there are equal numbers of positively and negatively charged droplets the probability of the drop colliding with a positive droplet is the same as the probability of it colliding with a negative droplet. The statistical distribution of charge may, therefore, be worked out in a manner precisely like that used to determine the charge on the cloud droplet when it was bombarded by ions. The exact process is well illustrated by Table IV. The fundamental difference between the electrification of the cloud droplet and the raindrop is that the cloud droplet encounters ions by virtue of their thermal agitation, whereas the raindrop is bombarded as a result of the relative gravitational motions of the large raindrop and the small electrified droplets.

Two raindrop electrifying regimes by droplet association are evident. The initial or nonequilibrium regime describes the early stages of electrification and is descriptive as long as the probability of collision of a droplet with a charged drop in constant. This regime is gradually converted into the equilibrium regime which is established whenever accumulated raindrop charges become large enough to control the probability of collision.

#### The Initial or Nonequilibrium Regime

Whenever the number of collisions between the raindrop and the cloud droplets is limited and the probability of collision is constant, the average charges for the distributions illustrated by Table IV may be estimated by use of the binomial point equation of statistical theory. It has been shown [32] that the mean non-equilibrium charge accumulated on raindrops  $\hat{Q}$ , averaged without regard to sign, is nearly

$$\hat{Q} = \left[ \frac{2K}{\pi} \right]^{1/2} \bar{q} \tag{25}$$

where K is the number of collisions that establish the charge on the raindrop and  $\bar{q}$  is the mean charge on the parent droplets, irrespective of their sign. The value of  $\bar{q}$  may be given by (20) or by (24). Since K may be large it is clear that very large drop charges may sometimes accumulate.

In the special case where there are more cloud droplets carrying one kind of charge than the other, and their numbers per unit volume are  $C_+$  and  $C_-$ , it is found [32] that the mean systematic charge  $\overline{Q}$  accumulated on the raindrops averaged with respect to sign is

$$\overline{Q} = \left( \frac{\frac{C_{+}}{C_{-}} - 1}{\frac{C_{+}}{C_{-}} + 1} \right) K\bar{q} = \frac{K\bar{q}}{2} \ln \left( \frac{C_{+}}{C_{-}} \right)$$
 (26)

where the logarithmic form is applicable only when  $C_+$  and  $C_-$  are not too different. The above nonequilibrium expressions for the raindrop charges are of value only when the number of collisions can be specified. Although other assumptions are possible, it is illuminating to suppose that the number of collisions is determined only by the ratio of the mass of the final drop to the mass of the average colliding cloud particle. Under this condition the random specific charge or the charge per unit mass accumulated on the falling rain, when averaged without regard to sign [32], is given by

$$\frac{\hat{Q}}{m_2} = \left[\frac{2fm_1}{\pi m_2}\right]^{1/2} \frac{\bar{q}}{m_1} \tag{27}$$

where  $\bar{q}/m_1$  is the random specific charge carried on the parent droplets,  $m_1$  and  $m_2$  are the masses of the cloud and raindrops, respectively, and f is an unknown factor that measures the evaporation, breakup of the drop, etc., and approaches unity when these factors are negligible. In a similar way the systematic specific charge transferred to the falling rain is [32]:

$$\frac{\overline{Q}}{m_2} = \left[ \frac{C_+ - C_-}{C_+ - C_-} \right] f \frac{\overline{q}}{m_1}.$$
 (28)

This expression shows that the systematic specific free charge is conserved during drop growth.

#### The Equilibrium Electrification of Raindrops

When there are sufficiently large numbers of collisions with the cloud droplets or when the cloud droplets are highly electrified an equilibrium distribution much like that given in (19) may be established. The fractional number of raindrops carrying integral multiples of the mean cloud droplet charge  $\bar{q}$  is essentially a Gaussian distribution. This distribution is normally symmetrical about the zero charge axis whenever equal numbers of positive and negative cloud droplets are encountered, but may be radically skewed towards positive or negative charges when the population densities  $C_+$  and  $C_-$  of the positive and negative parent cloud droplets are appreciably different. When equilibrium is established one may show [24, 25] from the mathematical analysis that

$$D_{\Omega_{q}^{-}} = \frac{D_{t}\bar{q}}{\left[\frac{\pi(r_{1} + r_{2})U_{R}^{2}}{2\left(\frac{1}{m_{1}} + \frac{1}{m_{2}}\right)}\right]^{1/2}}$$

$$\cdot \exp \left\{\frac{-\left[\Omega\bar{q} - \frac{(r_{1} + r_{2})U_{R}^{2} \ln (C_{+}/C_{-})}{4\bar{q}(\{1/m_{1}\} + \{1/m_{2}\})}\right]^{2}}{\frac{(r_{1} + r_{2})U_{R}^{2}}{2\left(\frac{1}{m_{1}} + \frac{1}{m_{2}}\right)}}\right\}. (29)$$

In this expression  $D_t$  is the total number of raindrops per unit volume,  $D_{\Omega q}$  is the number per unit volume carrying a charge  $\Omega \bar{q}$ ,  $\bar{q}$  is the mean parent droplet charge, irrespective of sign,  $\Omega$  is an integral number,  $m_1$ ,  $m_2$  and  $r_1$  and  $r_2$  are the masses and radii of the cloud and raindrop respectively and  $U_r$  is the relative velocity of the two types of drops. The ratio of the number of parent positive cloud droplets to those carrying negative charges is  $C_+/C_-$ . It may be noticed that this expression is similar in form to (19) and analogous to it in many ways. Thus one may calculate the mean charge on both the positive and negative fractions of the falling rain and show that this charge is given [25] by

$$Q_{+} = \left[ \frac{\pi (r_{1} + r_{2}) U_{R}^{2}}{8 \left( \frac{1}{m_{1}} + \frac{1}{m_{2}} \right)} \right]^{1/2} = \overline{Q}_{-}.$$
 (30)

Like (19) this may also be rewritten to show that an approximate *equipartition* is established wherein the electrical potential energy carried by the average falling raindrop is equal to the energy of bombardment by the smaller cloud particles.

One may emphasize that the equilibrium charge described by the above equations is not always established in ordinary rain because of the limited distance of fall or limited numbers of collisions. This is particularly true when the cloud droplets are weakly electrified as by ionic diffusion. As a rough guide, the equilibrium distribution of (29) and (30) may be used whenever a mixture of highly electrified droplets is produced as by induction. The nonequilibrium expressions of (27) and (28) are used when the droplets are weakly electrified as by the diffusion processes. No general rule is applicable and a special examination must be made in doubtful cases [32].

#### MAXIMUM ACCUMULATED DROP CHARGES

In an earlier analysis of the electrical charges measured on the ground and on aircraft flying through active thunderstorms, it was pointed out that the raindrop electrification processes must be extremely energetic because large numbers of drops of both signs were observed, each of which carried charges so large that the electric field at their surface was an appreciable fraction of the dielectric strength of air [14]. Reference to Table II will show that direct measurement of the charge on thunderstorm rain suggests charges approximating  $\pm 0.1$ esu/drop. Now, if the drop corresponds to "medium rain," its radius will approximate 5 × 10<sup>-2</sup> cm. The electric field at the drop's surface, therefore, is about 40 statvolt/cm or 12,000 volt/cm. When one reflects that such drops approach small conducting cloud particles that may locally concentrate the electric field, and notes further that the drop is frequently deformed as a result of aerodynamic forces, it is clear that adequate fields may exist at the drop surface to produce a corona discharge. Actually, the conditions necessary to induce

corona are more complex than the above statement implies. It has been long known that a certain minimum voltage is necessary as well as a large electric field. In small droplets the voltage is so low that electric fields exceeding the normal dielectric strength of air will not cause discharge but drops as large as the example used above may very well exceed the critical value and transfer by corona discharge any excess charge to the surrounding air [14]. It seems clear from the data in Table II and from other measurements made in active thunderstorms near the rain-forming levels, that many of the larger raindrops are "fully charged" by the acting electrification processes.

### Free Charge Distributions and Their Separation

Whenever equal amounts of positive and negative electricity are found within a given volume, it is neutral and no systematic electric fields are produced. In a thundercloud consisting of a mixture of highly charged raindrops, electrified cloud droplets, and ions, it is not likely that such a condition of exact neutrality will long persist. Consider a great neutral sheet of rain and cloud droplets. The rain falls faster than the cloud particles and an initial neutrality is shortly replaced by a free charge distribution. For example, negative charges largely carried by rain generally appear near the bottom of high level clouds while positive charges are likely to remain above. By considering a vertical prism of unit cross section extending from the ground through the thundercloud one may calculate the electric field E and the total charge per unit area within the prism by integrating Poisson's equation

$$E = 4\pi \int \rho dz = 4\pi\sigma + E' \tag{31}$$

where  $\rho$  is the free charge per unit volume,  $\sigma$  is the integrated free charge per unit area, and E' is the constant of integration determined by the surface charge. In this way one may formally determine the field in terms of the separated free charges on the precipitation and on the ground [10].

In addition to the free charges carried inside the cloud there are invariably charges induced on the conducting ionosphere and on the earth below. These induced charges play an important role in transferring electricity to the earth. The induced and free charge per unit areas within the prism are usually so adjusted that the total is approximately zero. In typical cases the electric field within the active region of the thunder-cloud is downward. But near the ground and above the cloud, the field is positive and outward. Sometimes the whole configuration is reversed. Usually the separation of free charge establishes fields that not only induce charges on the high atmosphere and the ground but simultaneously transport ions towards charge centers

and thus establish space charge sheets that act to limit the intensity of the electric field as measured at the earth's surface. This effect is prominent in the observed reversal of the field after a lightning stroke (Fig. 1).

According to the direct measurements reported in Table II above, the rain inside an active thunderstorm may consist of nearly equal numbers of positively and negatively charged drops or in some cases drops carrying a single sign are observed. When a matrix consisting of equal numbers of equally charged positive and negative drops are present in the air and both types fall at the same velocities, it is clear that no free charge separation or electric fields are produced. On the other hand, if the larger raindrops carry predominantly charge of one sign, neutrality of any given volume of space cannot be maintained and the big drops carrying their selected charge will fall, leaving their neutralizing charges of opposite sign to fall at a slower rate. A progressive separation of free charge by this means steadily increases the electric field. The accumulation of separated free charge cannot continue for long, because according to (31) electric fields of progressively greater intensity are immediately established and these fields interacting with the charge on the droplets produce electrical forces that act to oppose and limit the separation. In some cases these forces are adequate to support many of the raindrops against the forces of gravity [10].

One may emphasize that in most cases the free positive charges are never completely separated from the free negative charges. For example, in a mild cold front exhibiting charges like those summarized in Table III, it was found that the free charges corresponding to those measured on the large drops and distributed through a spherical volume a kilometer or so in radius would establish electric fields at the surface of the sphere many times as large as that actually measured. This shows that the charge separation is incomplete and that, in nature, there is always a mixture of positive and negative charges. However, one sign may be somewhat in excess [17]. This same conclusion is reached by calculatint the approximate free space charge density from the observed space gradients of the electric field values, and comparing this value with the free charges directly measured on the precipitation. The charge on the precipitation alone is again several times the net space charge showing that neutralizing charges, not measured by the raindrop analyzing equipment are present and mixed with the highly charged rain. Thus it is always necessary to distinguish carefully between the drop space charge density and the net space charge density [12].

According to the foregoing observations made inside actual storms one is brought to the view that a typical thunderstorm cloud is composed of large amounts of free charge of both signs carried partly by large raindrops, partly by small cloud droplets, and partly by ions. In this matrix, the heavily charged raindrops always fall towards the earth and when they carry charge

predominantly of a single sign, then a convective or transport current is produced carrying charge towards the ground and separating free charge. The magnitude of this convective current density [18] is given by

$$i = \Sigma N_{+}Q_{+}V_{+} + \Sigma N_{-}Q_{-}V_{-} = \rho \overline{V}$$
 (32)

where  $N_+$  and  $N_-$  are the numbers of large raindrops per unit volume carrying positive and negative charges respectively. Q is the charge on each,  $V_\pm$  is the velocity of fall of the drops;  $\rho$  is the net free space charge density; and V is its effective falling velocity. The velocities of fall for large drops is primarily determined by the aerodynamic forces and by gravity. But the smaller drops develop lower velocities that may be somewhat influenced by the electric fields.

It is clear from the foregoing paragraphs that gross electrification is not likely to be established within a cloud unless some mechanism selectively transfers free charge to the larger raindrops. One has, therefore, to examine the possible processes which can transfer free charge to rain. That such selective charging frequently occurs is fully demonstrated [12, 17, 19] by detailed plots of the summarized data. For example, in both the thunderstorm in the mild cold front mentioned above, regions were observed wherein the large precipitation elements all carried charges of the same sign. Neutralizing charges doubtless were associated with these but were attached to the smaller particles that would fall at a very much slower speed. Thus, according to (32) a net convective current is established.

Hyperelectrification provides an energetic mechanism for placing charges, all of one sign on large number of raindrops. We have shown that near the boundaries of electrified clouds, ions of a selected sign are concentrated; these ions are transferred to the polarized raindrops immersed in the layer and selectively charge them to a value given by (22). Now within the boundary space charge layer the positive and negative light ion conductivities are normally much different so that the drop charges are generally of one sign.

The number of raindrops or snow flakes in unit volume is determined by the liquid or crystalline water content (LWC) of the cloud and the droplet mass, so that the convected current density i of (32) in the case where all drops carry the same sign of charge, as for example, in hyperelectrification, is

$$i = (LWC) \frac{Q}{M} V \tag{33}$$

where the velocities of fall V may be determined nearly enough from available Tables of terminal velocities [16].

Earlier paragraphs have noticed that a mixture of highly charged positive and negative raindrops can be established either by induction in an electric field or by the association of large numbers of oppositely electrified cloud or rain droplets. Irrespective of the processes whereby such a mixture is produced, drops, falling down through an atmosphere wherein the positive and negative light ion conductivities are different, will selectively discharge drops of one sign more rapidly than they will discharge those of the opposite sign. This process results in the accumulation of raindrops at lower levels having a predominant free charge [27]. Whenever the initial specific charge of the mixed raindrops is sufficiently large and the differences in electrical conductivity are considerable, the convected current densities are large enough to establish measurable electrical activity [27]. The difference in conductivities between the positive and negative ions is established only for clear air as shown by (11) and (12) but there is accumulating evidence [37, 39, 43] to show that the conductivities are frequently much different inside natural clouds or in precipitating regions. Whenever the raindrops fall some kilometers in an atmosphere wherein  $\lambda_{+}\neq\lambda_{-}$  we have been able to show that the current density established by the above differential discharge processes is given roughly by [27]:

$$i = \frac{\text{LWC}}{2} \left( \frac{Q}{M} \right) V \left[ \exp\left( -1 \right) - \exp\left( \frac{-\lambda_{+}}{\lambda_{-}} \right) \right]$$
 (34)

where  $\lambda_+/\lambda_-$  is the ratio of the conductivities of the environment through which the drops fall.

It is convenient to recognize that the product of the liquid water content and its effective velocity of fall corresponds to the mass precipitation rate P expressed in terms of grams per square centimeter per second and therefore the convected current density may always be represented by an expression of form

$$i = (LWC) \frac{Q}{M} V \phi(\lambda_{+}/\lambda_{-}) = P\left(\frac{Q}{M}\right) \phi(\lambda_{+}/\lambda_{-})$$
 (35)

where the function  $\phi(\lambda_+/\lambda_-)$  measures the fraction of the total drop charge Q that is preserved as a free or systematic charge. This fraction depends on the particular drop electrifying mechanism and commonly approximates values from 0.05 to 1.0.

The energetic processes capable of highly electrifying rain that is exposed to electric fields have been emphasized above. There are, in addition, other electrification means that may contribute to the establishment of thunderstorm activity. For example, melting hail may place an excess positive charge of more than 1 esu on each gram that melts and falls to lower levels [4]. Similarly, the selective transport of ions to cloud droplets in regions where the positive and negative light ion conductivities are notably different can, according to (21), produce specific charges of 1.0 esu/gm under favorable conditions [26]. This latter process is of some importance in describing the initial electrification induced by low level nonthunderstorm rain.

PROCEEDINGS OF THE IRE

### EQUILIBRIUM ELECTRIC FIELDS AND THE REGENERATION TIME

Because electric fields are easily measured, it seems important to express the charge transferring processes in terms of the established field. Consider for example the downward transfer of a horizontal sheet of negatively charged raindrops and assume that the positive charge remains essentially fixed on the smaller cloud droplets above. Earlier articles [18, 20] considered the equilibrium in a vertical prism of unit cross section extending from the earth through the thundercloud. It was shown that in this prism

$$\frac{1}{4\pi} \frac{dE}{dt} + \lambda E = \Sigma NQV = \rho \overline{V} = i. \tag{36}$$

The first term expresses the accumulation of free charge per unit area below a selected reference plane, the second term the conduction current density, and these are equal to the convective current density *i*. The solution of (36) is

$$E = \frac{\rho \overline{V}}{\lambda} [1 - \exp(-4\pi\lambda t)] + E_1 \exp(-4\pi\lambda t)$$
 (37)

where E is the generated electric field at the reference plane,  $E_1$  the field at the plane when t=0,  $\lambda$  the total electrical conductivity of the environment,  $\rho$  the net free charge density carried by the large raindrops, and  $\overline{V}$  is the fall velocity of the heavy drops relative to the much smaller ones that carry the neutralizing or partially neutralizing charges. It is clear from (36) that when an equilibrium electric field is established, the charge accumulating below the reference plane approaches zero and the downward convected current density is just balanced by the upward conduction current density. Thus the equilibrium electric field approximates

$$E_e = i/\lambda = \frac{\rho \overline{V}}{\lambda}$$
 (38)

Now immediately, after a lightning discharge,  $E_1$  is small and therefore by (37) one has approximately

$$\left(\frac{dE}{dt}\right)_0 = 4\pi\rho\overline{V} = 4\pi i. \tag{39}$$

Here  $[dE/dt]_0$  is the *initial* rate of increase of the electric field just after the thundercloud has been neutralized by a lightning discharge. Thus, if the electric field recovers logarithmically as suggested by (37), the time  $\tau_R$  it will take the convection current to raise the electric field to a value  $E_c$  is given by [20]:

$$\tau_R = \frac{E_c}{4\pi i} = \frac{E_c}{4\pi \rho V} \cdot \tag{40}$$

It is illuminating to identify this critical field  $E_c$  with the dielectric strength of air and then  $\tau_R$  may be identi-

fied with the time to regenerate an electrical state capable of producing a lightning discharge. By the use of this expression one may formally express the lightning discharge frequency as a function of the net convected current density and the critical dielectric strength of air. In this way one may plot Fig. 17 giving the discharge frequency as a function of the activity index defined as  $\rho \overline{V}/\lambda E_{\sigma}$  [20].

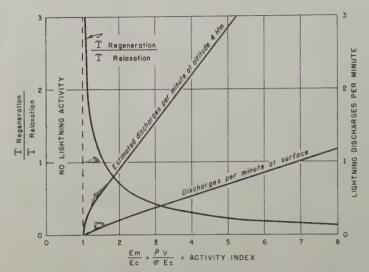


Fig. 17—Estimated relation between the electrical activity index, the lightning recurrence frequency, and the ratio of the regeneration to relaxation times.

For short discharge paths it is well known that the dielectric strength of air is something like 20,000 volt/cm but as the path length increases and electron avalanches develop the dielectric strength steadily decreases to about 4500 volt/cm at ground levels [40]. At higher levels it is systematically less. This value of  $E_c$  has been adopted in calculating Fig. 17.

If the atmosphere were a perfect insulator with an extremely high dielectric strength, only selectively charged raindrops would fall, and thus separate free charge until an electric field was established that would either drag downward the lighter particles left overhead or the raindrops would be supported by the field. One may calculate the electric field required to support the droplets and it is found that the required field is in excess of 25,000 volt/cm and greatly exceeds any gradient that can continuously be maintained in ordinary air [18]. This means, in general, that true equilibrium fields seldom fully mature in heavy rain regimes because lightning discharges intervene.

### THE INITIAL ELECTRIFICATION OF ALL PRECIPITATING CLOUDS

The crucial problem of precipitation electricity is to describe how light rain falling from a neutral cloud usually initiates electric fields of from +10 to +30 volt/cm at the earth's surface. It is true that an all pervading fair weather electric field exists over the earth

and presumably has appreciable values at all levels even within a neutral cloud. Therefore, if regenerative mechanisms are invoked to describe the high, subsequently developed fields, this residual field may be of theoretical significance. Actually the presence or absence of a small initial field is not considered important since electric fields may be established in a cloud which is at first entirely neutral and by other straightforward energetic processes.

It is emphasized again that ions are always produced in pairs and that the mobility of the negative ion in clean air is some 40 per cent larger than that for the positive ion. This provides a fundamental mechanism for establishing a higher conductivity for the negative ions than for the positives, in those regions where suspended particulate matter is a minimum. Observations clearly show that the condensation and sublimation nuclei density normally decreases very rapidly with altitude [35]. Therefore, at rain and snow forming levels, one might anticipate that the number of precipitation particles per unit volume would be low and the negative conductivity would be notably larger than the positive conductivity. This difference has been observed by a number of investigators in clear air and therefore, according to (21), one would expect snow flakes or water droplets at high levels to carry an excess negative free charge.

Now it has been possible to determine the ratio of the positive and negative ionic conductivities from a knowledge of the number of cloud droplets per unit volume, their radius, and the rate of ion pair production. This ratio determines the free charge carried on the droplets through (21). Thus, in the special case when the cloud droplet or snow flake density is low, appreciable net electrification is induced by the difference in ionic conductivities. To illustrate the initial electrification processes, consider an example. Published data on the size of falling snow flakes show that a typical snow flake radius is 0.05 cm and its mass approximates  $8 \times 10^{-6}$  gms [34]. Now when the condensed water content approximates a typical 10<sup>-6</sup> gm/cm<sup>3</sup>, the number of snow flakes per unit volume is 0.12 so that Na approximates 0.006. Thus, at snow forming levels  $N^2a^2/q$  approximates  $3.6 \times 10^{-6}$  and by Fig. 15,  $\ln \lambda_{+}/\lambda_{-} = -0.12$ . By use of (21) it is found that the systematic negative charge transferred to the typical snow flakes by ionic diffusion is  $Q = -5.2 \times 10^{-7}$  esu and the specific charge approximates O/M = -0.065 esu/gm. In a similar way one may show that the large rain initiating droplets produced by condensation at levels where the air is relatively free of pollution will produce specific charges of comparable but somewhat larger magnitude. As noted in (26), the systematic specific free charge is conserved when the melted or newly formed droplets associate to form larger raindrops. Accordingly, it is evident that, when these droplets coalesce and fall towards the ground, they will transfer negative charge downward. It remains only to

determine the magnitude of the electric field that these electrified drops may produce.

By substituting the values suggested in the above paragraph in (21), assuming that liquid or crystalline water content is 10<sup>-6</sup> gm/cm<sup>3</sup>, and that the drops grow large enough to fall at a velocity of 400 cm/sec, then it is found by (33) and (38) that at 2-km altitude where  $\lambda = 4.10^{-4}$  esu, that  $E_c = +0.06$  statvolt/cm = +20volt/cm. Such an electric field is the same sign and approximate magnitude as the field commonly observed whenever stratus clouds of modest depth precipitate. The field is more than an order of magnitude larger than the fair weather field and is in the direction of commonly observed electric fields in thunderstorms just prior to a discharge. We consider it adequate to excite all the induction and hyperelectrification effects mentioned in the foregoing paragraphs and thus initiate through further regeneration full scale lightning activ-

Electrification of drops by the above process also takes place in the lower levels of the atmosphere but the charges here are predominantly positive because of the excess conductivity of the positive ions. This special case has been considered [26].

#### CRITERIA FOR THE ESTABLISHMENT OF HIGH ELECTRIC FIELDS BY REGENERATION

The foregoing section has shown how the diffusion of ions onto falling precipitation may sometimes establish initial electric fields approximating +20 volt/cm. Such a field does not depend on the presence of an initial electric field or upon influence effects.

According to (22) and (24), large charges are transferred to raindrops whenever electric fields are present and these charges are proportional to the impressed electric field. It is important to determine whether the charge so produced can maintain or actually increase an initial field of moderate intensity.

Let the charges transferred to rain by the various influence processes considered above be represented by

$$O = 3BE_0 a^2 \text{ esu} \tag{41}$$

where B is a numerical constant of the order of unity which depends upon the specific electrifying process and upon the relative values of the average and maximum charges actually produced. The charge per unit mass, accordingly, is given by

$$\frac{Q}{M} = \frac{9BE_0}{4\pi ad} \text{ esu/gm.} \tag{42}$$

Thus, by (35), (38), and (41) one finds that

$$\frac{E_e}{E_0} = \frac{(\text{LWC})VB\phi\left(\frac{\lambda_+}{\lambda_-}\right)}{4\pi da\lambda} = \frac{9B\left[\phi\left(\frac{\lambda_+}{\lambda_-}\right)\right]P}{4\pi da\lambda} \tag{43}$$

where P is the mass precipitation rate in gm/cm<sup>2</sup>sec and  $\phi(\lambda_{+}/\lambda_{-})$  represents the functional dependence of

(22) or (24) on the conductivity ratio. This function is also dependent upon the drop radius a.

It is clear that if the generated electric field  $E_{\rm e}$  is greater than the electric field  $E_{\rm 0}$  which transfers charge to the raindrops, then the drop charges will increase and the electric field can steadily increase or regenerate until the dielectric strength of air is surpassed. Accordingly, the criterion for the regeneration and establishment of large fields within a thundercloud from a small initial intensity is that (43) be greater than unity, or that

$$\frac{(\text{LWC})V}{\lambda a} \phi \left(\frac{\lambda_{+}}{\lambda_{-}}\right) = \frac{P\phi(\lambda_{+}/\lambda_{-})}{a\lambda} > \frac{4\pi d}{9B} \doteq 2.8. \quad (44)$$

For the purpose of illustration, it is convenient to adopt numbers that describe the critical case; note that precipitation rates and free charges larger than this critical value will permit regeneration while lesser values will degenerate. Thus, in this critical case one may adopt as representative B/d = 0.5,  $\phi [\lambda_+/\lambda_-] = 0.5$ ,  $\lambda$  at 2 km =  $4\times10^{-4}$  esu, so that P=0.0022a gm/cm<sup>2</sup> sec. Thus if a = 0.05 cm corresponding to "medium rain" then P = 0.4 gm/cm<sup>2</sup>hr = 0.4 cm of H<sub>2</sub>O/hr. Such precipitation rates and liquid water contents (LWC) are frequently exceeded. It is clear from these figures that regeneration and build up to high electric fields cannot occur unless the precipitation rate exceeds that of typical "medium rain" and unless  $\phi[\lambda_{+}/\lambda_{-}]$  is some appreciable fraction. The writer believes that this is a proper conclusion because the data clearly show that heavy precipitation is not always accompanied by lightning. It is noteworthy that large precipitation rates act to accentuate any electrical activity already present.

It would be improper to conclude that gross electrification phenomena can only develop through influence effects, but since these are clearly regenerative under certain conditions and are especially energetic we consider them to be of some importance.

### THE ESTIMATED ELECTRIFICATION IN ACTIVE THUNDERSTORMS

The foregoing sections have outlined some of the basic electrical phenomena taking place in the earth's lower atmosphere. The differences in conductivities of the positive and negative ions contribute to differential discharge and electrifying processes that ultimately develop free charges on the falling rain. One now considers the over-all behavior and electrical magnitudes within an active thunderstorm.

It has been shown how an initiating positive electric field of about +20 volt/cm could be established by light rain falling to the ground. This initial field is capable of being regenerated and built up by influence effects operating on the falling rain. To illustrate the basic processes, one considers two examples of charge transfer and electric field production that are so energetic that they probably play a major role in establishing the ob-

served electrical state. These processes and possibly others frequently act simultaneously so the electrification of a thundercloud as a whole is likely to be complex.

Consider first a vertical prism of unit cross section extending to high levels where snow flakes and ice crystals are formed and fall towards the melting level. At these high levels the suspended contamination is normally small and some systematic electrification due to ionic diffusion will be produced just as suggested previously. However, quite independent of these diffusion processes the snow crystals will frequently collide and separate. When the separation takes place in an electric field we have seen that large charges of opposite sign are produced on the separated snow crystals. For the purpose of estimation suppose that the ice crystals have a radius that is typically 0.05 cm and that they are favorably oriented with respect to an electric field  $E_0$  at the time of their separation. The magnitude of the positive and negative induced charges by (24) is then  $8 \times 10^{-3}$ E<sub>0</sub> esu. Now when this mixture of highly charged ice crystals carrying both positive and negative charges fall to the melting level and are there converted into water droplets further collisions will result in association to form a distribution of highly charged raindrops related to that shown in Table IV. It is estimated that some 65 associations between such small melted ice crystals will take place before they grow into a "medium raindrop" having a radius of 0.05 cm [34]. Thus, by use of (25), one may calculate the mean multiplied drop charge, averaged without respect to sign, as  $5.1 \times 10^2 E_0$  esu. The specific charge carried by such associated raindrops is 96  $E_0$  esu/gm. A short calculation will show that the ratio of the electric field at the surface of the drop to the exciting field  $E_0$  is 20. Thus, if the exciting field  $E_0$  is as much as 2 statvolt/cm the field at the drop surface will approximate 12,000 volt/cm. Any additional charge may well induce corona and thereby limit the drop charges. This example suggests that the electrification by induction and their subsequent association will "fully electrify" the produced droplets whenever the original induced electric field much exceeds 2 statvolt/cm. Attention is drawn to the fact that nearly equal numbers of positive and negative drops are produced by this process. However, as this mixture of positive and negative drops falls in the atmosphere the conductivity measurements [7, 37, 39, 43] together with the measurements on the discharge characteristics of our flying laboratory, Fig. 9, show that they will discharge selectively. Thus when the mixture of drops falls some 2 or 3 km an excess free charge is established having a sign corresponding to the ions exhibiting the larger conductivity [27]. At levels above 3 or 5 km the negative ion conductivity is in excess and drops falling through this region would accumulate a negative free charge. Below 3 or 5 km there would be a marked tendency for the drops to accumulate a positive free charge [26]. Now when the ratio of the conductivities  $\lambda_+/\lambda_-$  approximates

0.9 the differential discharge of the raindrops will establish thereby an excess negative free charge that is transferred toward the earth with a velocity corresponding to the terminal velocity of "medium rain," or 400 cm. Thus when LWC= $10^{-6}$  gm/cm³ one may calculate the convected current density by (34) and it is found to approximate  $7\times10^{-4}$   $E_0$  esu/cm². The reader may verify that such a current density summed up over the entire area of a typical thunderstorm will establish a total convection current of more than one ampere if  $E_0$ =2 statvolt/cm. Such a current approximates the measured currents [7].

One may estimate from (38) the equilibrium electric field that will be established as a result of the convected charge moving towards the ground. At a selected height of 2 km one may adopt a conductivity for clear air of  $4 \times 10^{-4}$  esu or  $4 \times 10^{-5}$  esu within a typical stable cloud. Thus by (38) the established equilibrium electric field would approximate 1000 volt/cm in clear air or 10,000 volt/cm within a cloud. Because of uncertainties in the conductivity and the physical properties of the falling rain exact numerical values are unimportant, but one may notice that the charge transferring processes are adequate 1) to regenerate the initial field and 2) to establish electric fields and gross currents within the thunderstorm that are descriptive of the available observations. Whenever the electric field exceeds about 4500 volt/cm at the earth's surface or something less than this value over an extensive path, observations show rather clearly that a disruptive lightning discharge will be initiated [40]. Accordingly, one may understand in quantitative terms one of the basic mechanisms that is capable of establishing lightning.

Consider another energetic mechanism of somewhat different type and suppose that some free charge already exists within the thundercloud. We have seen that hyperelectrification is important at the boundary of discontinuity between the thundercloud and the clear air outside. This mechanism has been discussed in some detail [29] and leads to drop charges of magnitude given by (22). According to this expression, high charges all of one sign are transferred to the raindrops in the transition layer. To illustrate the process, assume that the precipitation is characterized by "medium rain" and the drop radii approximate 0.05 cm. Thus, the charge on each drop by (22) is  $7.5 \times 10^{-3} E_0$  esu. When  $E_0$  is large enough the drops may again carry charges comparable to the maximum as discussed previously. Further assuming that the liquid water content is a typical 10-6 gm/cm<sup>3</sup>, the space charge density will be  $1.5 \times 10^{-5}$   $E_0$ esu/cm³ and this falls towards the earth at the velocity of fall for "medium rain." Therefore, the convected current density is  $6 \times 10^{-3} E_0 \text{ esu/cm}^2$  and the total current for a typical thunderstorm may be several amperes. The precipitation charge in the above example is all of one sign and could have been calculated directly from (33). Again noticing that the equilibrium electric field is

determined by the convected current density and the conductivity one may again substitute the conductivity at 2 km or  $4 \times 10^{-4}$  esu to show that the equilibrium field is  $15 E_0$  statvolt/cm or  $4500 E_0$  volt/cm. Thus if  $E_0$  has typical values the falling rain is capable of establishing an electric field, even in clear air, which is greater than the dielectric strength of air. Further, one may notice that if a lower conductivity, characteristic of stable clouds, is employed the equilibrium field would be much larger than that just calculated and the field would then far exceed the dielectric strength of air. In any event, lightning is likely to intervene, which will equalize the separated charges.

The above electrification processes are exceedingly energetic and are thought to be principally responsible for the observed separation of free charge in a thunderstorm. It is important to recognize that the sign of the charges produced by hyperelectrification depends on the direction of the electric field at the cloud boundary. When the cloud boundary sees positive charge within the cloud the drops are likely to be negatively charged but if the boundary sees negative charge within the cloud the drops will be positively electrified. It is clear, therefore, that some thunderstorm regions will be characterized by highly charged drops of one sign while other regions will contain highly charged drops of the opposite sign, just as Fig. 6 and our other aircraft measurements clearly show [17]. These aircraft measurements show that negative charges normally predominate on precipitation at the high rain forming levels. The excessive negative ionic conductivity commonly observed at such levels where the suspended pollution is a minimum suggests strongly that perhaps most of the marked sign selective processes considered in the foregoing sections may be fundamentally traceable to the superior mobility of the negative ion. This general view has influenced the interpretation of atmospheric electric problems since the classical measurements of ionic mobilities were first made in 1900 by Dr. John Zeleny.

# RELATION OF THUNDERSTORM ELECTRICITY TO THE EARTH'S FAIR WEATHER FIELD AND TO THE CLEANLINESS OF THE EARTH'S ATMOSPHERE

It is well known that the surface of the earth in all fair weather regions carries a negative charge of about  $4\times10^{-4}\,\mathrm{esu/cm^2}$ , and that this maintains an inward electric field of about 1.5 volt/cm. Wilson suggested long ago [45] that the maintenance of the observed fair weather charge and field was probably related to the presence of thunderstorms somewhere else on the earth. Probably most workers in the field of atmospheric electricity accept this explanation as correct because there are worldwide fluctuations of the fair weather field which appear to be in phase with the abundance of thunderstorms averaged over the earth. Gish and Wait [7] have estimated the current at the top of a thunder-

cloud where the current density measurements were not complicated by the convective transport of charge on rain, and they found currents approximating 1 ampere per thunderstorm. Since the current to the high atmosphere and the ground must be continuous a negative current of similar magnitude usually flows towards the ground just as we have estimated in the foregoing section. However, because of the relatively high resistance of these lower layers the transfer of charge across this layer is frequently augmented by lightning discharge. We have seen that typically 17 coulombs is transferred to the earth by each lightning discharge. This transfer is frequently supplemented by conduction currents and the charges on the falling rain so that the determination of exact quantities is rather difficult.

We have evidence suggesting that the transfer of charge from the clouds to the earth takes place with greater ease in mountainous regions because such mountains frequently extend well into the conducting atmosphere at high levels. The total currents transferred in mountainous regions is unknown but preliminary measurements suggest that it may be large and the matter deserves careful investigation. The general character of the equivalent electrical circuit in the atmosphere is outlined in Fig. 18.

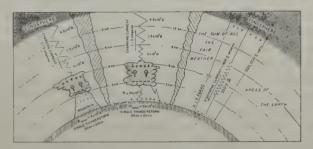


Fig. 18—Equivalent electrical circuit of the atmosphere. From 1000 to 2000 thunderstorms in constant operation are required to maintain the currents in the fair weather areas of the earth. Notice that charged raindrops transport the free charge through the cloud and provide the energy to establish the current.

One aspect of the maintenance of the earth's charge requires special consideration. Fig. 1 shows that in active thunderstorms the impressed electric field is more or less alternating in character and positive and negative fields are common. We have seen that space charge always accumulates in the lower atmosphere which is opposite in sign to the charge on the earth. An analysis shows that whenever time is available to accumulate space charge a positively charged surface will discharge more rapidly than a negatively charged surface. Thus, alternating electric fields impressed on the lower atmosphere will result in the transfer of more negative charge to the earth than positive. That is to say, the lower atmosphere has rectifying properties [9]. Even if the acting charge separating processes in the atmosphere were purely random in nature, it is clear that this earthly condenser would accumulate and maintain a negative charge. The magnitude of the rectified current would not fully account for the observed field unless thunderstorms are more general and cover more area than we now believe [9].

The fundamental importance of thunderstorm activity and the maintenance of the earth's fair weather electric field has never been adequately emphasized. It is clear that it plays no direct part in the over-all weather process but its secondary role in sweeping the atmosphere clear of fine particulate matter can hardly be overestimated. It is well known that the number of condensation nuclei decrease rather rapidly with increasing altitude and this has generally been attributed to gravitational fallout. With the advent of nuclear bombs the problem of cleansing the stratosphere of its suspended particulate matter is a very practical one. One may easily show that a particle of radius 10<sup>-6</sup> cm and carrying one elementary charge will experience a force, produced by the fair weather electric field in the stratosphere, that is roughly ten times as large as the gravitational force. Near thunderclouds the relative forces will be proportionately much greater. Accordingly, in the presence of clouds, or indeed in clear air, the superimposed systematic electrical motions communicated to the particles acts to precipitate out the very fine particles onto cloud droplets and on the ground. We do not suggest that the mechanism is important for particles as large as a micron because here gravity plays probably the major role but it is extremely difficult to understand how the tremendous numbers of very fine particles of the size of many condensation nuclei suspended in the atmosphere are purged unless electrical phenomena are invoked. Accordingly, this author believes that the role of thunderstorm electricity is an important one in making this earth a habitable abode for man.

#### Conclusion

The foregoing sections have summarized probably the most important phenomena responsible for the electrification of precipitation and thunderstorms. We have attempted to emphasize that thunderstorm electrification is but an extreme manifestation of the charges commonly produced on all precipitation. It seems clear from the data that large, newly formed raindrops are usually electrified but do not always produce lightning. Thus, one infers that there are secondary relationships related to the rate of precipitation and to the character of the cloud development which somewhat determine the electrical activity of the cloud. These relationships are specified by (44).

According to the above analysis the electrification is principally associated with: 1) Droplets or ice crystals formed in clean air at high levels. The process here is primarily one of selective diffusion. 2) Special phe-

nomena in the transition layer between a cloud and its clear air environment. In this layer, ions of a single sign from outside the cloud, are commonly concentrated and are deposited on cloud droplets and raindrops by hyperelectrification. 3) Electrical induction by the contact and separation of ice crystals or raindrops exposed to an electric field. The mechanism is such as to produce a mixture of positive and negative drops carrying roughly the same charge magnitudes. 4) The selective discharge of mixtures of positive and negative drops as they fall down through an environment wherein the positive and negative conductivities are different. All of these processes are energetically capable of contributing to the over-all electrification of a thundercloud. Some of these processes are evident in light rain and drizzle formed at low levels which is known to be weakly electrified [26].

It seems clear from the analysis that rapid regeneration and build up of the electric field accompanied by frequent lightning discharges can hardly be anticipated unless the precipitation rate exceeds that characteristic of "medium rain." All of these requirements appear consistent with the available knowledge on the meteorological characteristics of thunderstorms. Thus, the above quantitative description of thunderstorms is adequate to account not only for active thunderclouds extending to high freezing levels, but also in very clean air when the storm cloud fully develops below the freezing level. Moreover, the description does not require that lightning be produced by every heavily precipitating cloud. This summary attempts to discuss only the outstanding features of thunderstorms and because of their complexity exceptions must be anticipated.

Many of the processes which we have examined in this communication are directly applicable to the generation of volcanic lightning. The main requirement is that particulate matter collide, separate, and fall in a semiconducting ionized atmosphere. It is anticipated that lightning storms much like those observed on the earth will develop on other planets or on stars.

The analysis of atmospheric electric phenomena in precipitating regions has necessarily ignored a number of processes that have been considered adequately by other writers. Our research team has examined a number of suggested electrifying processes to determine roughly their relative importance in atmospheric electricity. Some of these processes doubtless contribute to the overall electrification under especially favorable conditions. But the mechanisms we have considered above all prove to be energetic and electrically active in the laboratory. Much more work needs to be done in this field of research and there is a large number of stimulating problems yet to be solved. This review is intended to emphasize those mechanisms that appear to the writer to be most important and to stimulate further work in this specialized area of basic physics.

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### An Improved High-Gain Panel Light Amplifier\*

B. KAZAN†, SENIOR MEMBER, IRE

Summary-A grooved photoconductor light-amplifying picture panel is described, whose gain is more than 10 times greater than any previous amplifier and whose threshold for input light is reduced. These improvements have been obtained with a new electrode structure which enables a more efficient type of operation and by the use of a more sensitive photoconductive powder. Measured input-output characteristics are shown comparing the new and earlier types of operation and also indicating the effects of different supply frequencies. The time-integrated energy gain for a one-second excitation is of the order of 100 with input light of the same spectral distribution as the output. The asymptotic energy gain after a longer excitation interval is about 800 with optimum spectral matching of the photoconductor. Although the decay time is of the order of seconds, as with early amplifiers, the shape of the decay curves and the rate of decay are changed by the new method of operation.

#### Introduction

THE basic design of the original panel light amplifier<sup>1</sup> is shown in cross section in Fig. 1. The principal layers are the electroluminescent phosphor layer which produces the output image and the photoconductive layer which varies its resistance in accordance with the input radiation. Since the photoconduc-

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† RCA, Princeton, N. J.

1 B. Kazan and F. H. Nicoll, "An electroluminescent light-amplifying picture panel," Proc. IRE, vol. 43, pp. 1888–1897; December, 1955. (Some of the results of this work were also described in Radio Age, vol. 14, p. 6; January, 1955 and by D. W. Epstein in RCA Eng., vol. 1, pp. 42–44; June–July, 1955.)

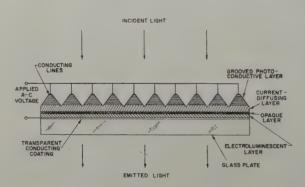


Fig. 1—Basic design of grooved photoconductor light amplifier.

tive layer in the dark must be many times higher in impedance than the electroluminescent layer, it is made much thicker. To efficiently illuminate the thick photoconductor, it is grooved. In operation, the incident light is absorbed on the surfaces of the photoconductor so that photocurrents flow down the sides of the ridges and converge at the bottom of the grooves. To efficiently utilize the entire phosphor area, a resistive currentdiffusing layer is placed below the photoconductor. This spreads the photocurrents slightly, approximately one groove width. To prevent feedback of output light, an opaque insulating layer is provided on the back surface of the phosphor layer.

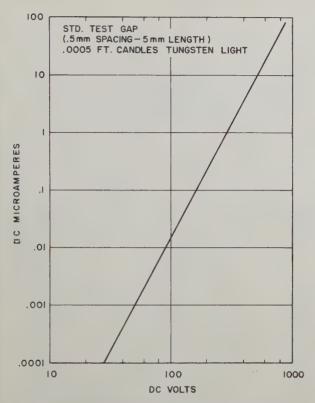


Fig. 2 -DC photocurrent vs voltage of photoconductive powder.

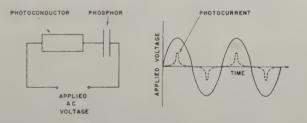


Fig. 3—AC operation of single element.

#### CONVENTIONAL METHOD OF OPERATION

The photoconductive material employed is an improved CdS powder bonded with plastic. The currentvoltage characteristic of this material is very nonlinear.2 Fig. 2 shows a log-log plot of dc current vs voltage for a fixed light level, indicating the current to vary approximately as the fourth power of the voltage over many orders of magnitude of current. One effect of the nonlinearity is a reduction in amplifier gain when operated in the usual manner with ac voltage. Fig. 3 shows a single amplifier element with sine-wave excitation. Because of the nonlinearity of the photoconductor, most of the current flows during a small portion of the cycle when the voltage is near its peak. Compared to a linear photoconductor with equal peak current, there is a reduction in average current for the nonlinear CdS powder with a corresponding reduction in output light from the phosphor layer. In operation, the peak voltage which can be applied to the photoconductor is limited by breakdown. With a given peak voltage level some improvement in operation is possible with the nonlinear CdS by using rectangular wave shapes which increase the average ac current. However, a much larger increase in current can be obtained by a different method as next indicated.

#### NEW METHODS OF OPERATION

If a dc voltage equal to the peak ac voltage is applied to the photoconductor, it is found that the dc photocurrent is usually many times greater than the peak ac photocurrent. This dc increase of photocurrent is a particular property of the CdS photoconductive powder. At the low-light levels used with the amplifier the increase in photosensitivity may be as high as 10 times.

While the photoconductor requires dc voltage for best operation, the electroluminescent phosphor layer requires ac voltage, being inoperative with dc. This difference cannot be reconciled by the simple series circuit which has been the basis of light amplifier operation until now.

One method of overcoming the problem is shown in Fig. 4, representing a single amplifier element. Instead of a single photoconductive element, two smaller photoconductors are used, both of which are assumed to be equally illuminated. In series with each photoconductor is a diode so that a half-wave rectified voltage of opposite polarity and phase is applied to the two photoconductors. The voltage polarity and phase are shown by the solid lines to the right, with the photocurrent pulses as dashed lines. In operation during a positive half cycle, the current pulse through photoconductor A charges the phosphor element positive. During the next half cycle, the current pulse of opposite direction through photoconductor B charges the phosphor element negative, developing ac voltage across the phosphor. Although pulsed dc voltage is applied to the photoconductors instead of steady dc, it is found that the peak photocurrent obtained is almost as great as with steady dc. This type of operation produces a large increase in ac voltage across the phosphor element for a given light flux in lumens falling on the photoconductive elements.

Using the basic principle of the rectified ac operation, further improvement is obtained with the circuit of Fig. 5. Here, instead of diodes, dc bias voltages of opposite polarity are inserted in series with the two photoconductive elements. By setting the bias voltage equal to the peak ac voltage, pulsating dc voltages of opposite polarity and phase are applied to the photoconductors. Since the width of the voltage pulses between half-value points is greater than for the rectified ac operation, the photocurrent pulses are wider than with rectified ac. Therefore, the average ac current through the phosphor is increased, and more output light is produced. Although the voltage applied to one photoconductor rises

<sup>&</sup>lt;sup>2</sup> F. H. Nicoll and B. Kazan, "Large area high-current photoconductive cells using cadmium sulfide powder," J. Opt. Soc. Amer., vol. 45, pp. 647–650; August, 1955.

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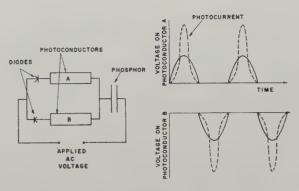


Fig. 4-Rectified ac operation of single element.

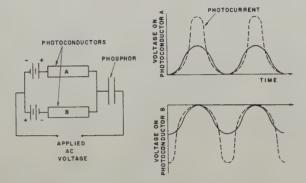


Fig. 5—Biased ac operation of single element.

before the voltage on the other photoconductor falls to zero, the current flow when the instantaneous voltage is low can be neglected for most input levels because of the nonlinear property of the photoconductors.

To apply the rectified ac or biased ac method of operation to the light amplifier requires a modification of the electrode system. Fig. 6 shows the cross section of the modified amplifier operated with biased ac. The conducting lines on the grooved photoconductor are separated into two interdigital sets, each set being connected to one of the two bias supplies. If light strikes the photoconductive layer, as shown, conductivity results on the surfaces of the grooves at the local area illuminated. The portions of the photoconductor and phosphor area corresponding to the single picture element of the previous figure are shown by the heavy lines.

#### COMPARISON OF OPERATING METHODS

The different modes of amplifier operation can be compared by means of the corresponding input-output characteristics. These cannot be measured, however, as static characteristics because of the build-up properties of the photoconductor. Fig. 7 shows a log-log plot of dc photocurrent vs time for different light levels using the grooved photoconductive layer of the amplifier with interdigital electrodes as a photocell. The procedure used before measuring each curve was to initially flood the photoconductor with a high light level and then allow it to decay. At the moment the dark current reached a specified level (approximately 4  $\mu$ amp), the input light for the measurement was switched on and the curve

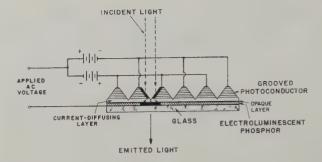


Fig. 6—Biased ac operation of light amplifier.

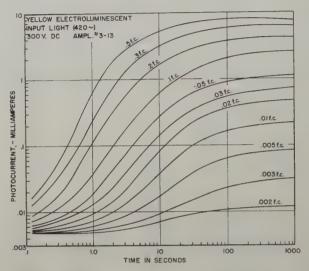


Fig. 7—DC photocurrent vs time for different input light levels.

recorded. Except for the very low light levels, a considerable portion of each curve is a straight line with a slope of about 2 indicating the photocurrent to rise as the square of the time. The time required for the individual curves to reach a specified fraction of their equilibrium levels depends on the input light level. This build-up time varies approximately inversely with the light level. At the higher voltage levels used in amplifier operation, the photoconductive layer has a sensitivity of about 40 amp/lumen (using low-level yellow electroluminescent input light peaked at about 550 millimicrons). Since more than 500 volts can be applied across the photoconductive layer (approximately 15 mils thick), it can control a power flow through it of >104 watt/lumen.

The effect of the photoconductor build-up on the amplifier operation is shown in the curves of Fig. 8 indicating output light vs time for different input light levels using biased ac operation. For a specific excitation time, the output light for different input light levels can be obtained from these curves. Such an input-output characteristic for a 10-second excitation time is shown in Fig. 9. For comparison, characteristics are also shown for the conventional ac and rectified ac methods of operation with a 10-second excitation time. The latter characteristics were obtained from sets of light output vs time curves similar to Fig. 8. In all of the measure-

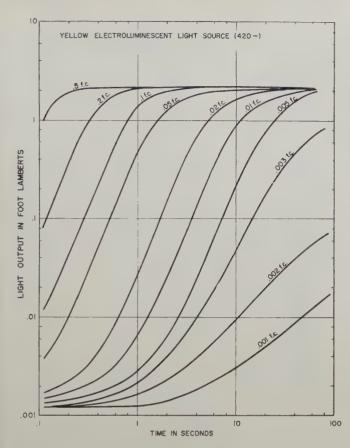


Fig. 8—Amplifier output vs time for different input light levels using biased ac.

ments of light output vs time, irrespective of method of operation, the amplifier was initially pre-excited and allowed to fall to a specified output level of 0.0012 footlambert before recording the curves.

All of the curves have high slopes with a gamma of about 3. For low-level input light the rectified ac operation gives about 20 times as much output light as the conventional ac operation. Using biased ac operation, more than 50 times as much output light is obtained compared to the conventional ac operation. Alternatively, with biased ac, about 5 times less input light is required to produce a given output light compared to conventional ac, thus lowering threshold of operation.

At the higher output levels the ac characteristic begins to saturate slightly. The saturation is greater for the rectified ac characteristic while the biased ac characteristic becomes completely flat. The saturating effects of the rectified and biased ac are not due to a saturation of the photoconductor, but are caused by a leakage of charge through the photoconductive elements during the half cycle when they are assumed to be nonconducting. The clipping action of the biased ac is of practical advantage in protecting the phosphor layer from breakdown. If the amplifier is accidentally excited with high input lights this limits the voltage which can be applied to the phosphor.

For longer or shorter excitation times than the 10 seconds shown, sets of similar-shaped characteristics

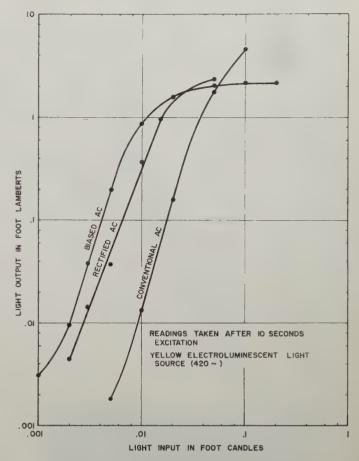


Fig. 9—Input-output characteristics for different methods of operation.

are obtained displaced to the left or right, respectively. With an excitation time of a minute, the curves of Fig. 8 show a maximum gain of about 400 times (0.005 footcandle input). These curves were obtained with a yellow electroluminescent input light source of identical spectral distribution as the amplifier output. Since the photoconductor is peaked in the red at about 750 millimicrons it is not efficiently excited by the phosphor, peaked at 550 millimicrons. Assuming an input light of about 750 millimicrons wavelength, the energy gain of the amplifier is about 800 times. Measurements with tungsten input light of about 2800°K indicate a gain in lumens of more than 1000 times with an excitation time of a minute.

#### COMPARISON OF OPERATING FREQUENCIES

The characteristics of Fig. 9 were obtained with 420-cycle ac. To determine the effects of operation at other frequencies, input-output characteristics were also obtained for 60 and 2000-cycle biased ac operation. Fig. 10 shows typical characteristics compared to a 420-cycle characteristic, all obtained with an equal excitation time. For comparative purposes the light output preceding excitation of the amplifier in all measurements was maintained constant (approximately 0.0012 footlambert). Except at high input levels, the 2000-cycle characteristic shows lower gain compared to the other

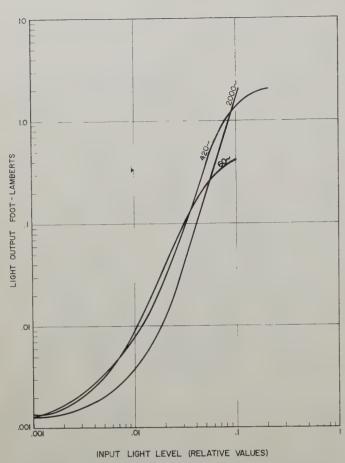


Fig. 10—Input-output characteristics comparing operating frequencies.

curves. A comparison of the 60-cycle and 420-cycle characteristics shows approximately equal gain for both frequencies at low levels but with greater output light obtained from the 420-cycle operation before saturation. The lack of higher gain in 60-cycle operation is explained by the rapid drop in sensitivity of the photoconductor with reduction in current level. For a given threshold output light (as used in the frequency comparison), the current level at 60 cycles is considerably below the 420-cycle level. For many purposes, the 420-cycle operation is a useful compromise, enabling high gains at low levels and moderate output light levels of approximately 1 foot-lambert.

### Decay Characteristics and Integrated Gain

In addition to its build-up properties, the present CdS photoconductor has a decay time of the order of seconds. Fig. 11 shows decay curves of the amplifier with ac operation for different levels of input excitation. Each curve was obtained by applying the input for one second and then allowing the amplifier to decay for the remaining time. About two to four seconds are required for the output to fall to one tenth its value, with the rate of decay greater for the higher input levels. At the highest input light level of 0.3-foot candle, the decay curve, shown as a

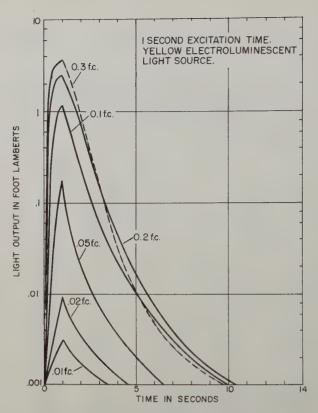


Fig. 11—Decay curves for ac operation.

dashed line, crosses below the lower curves. The increased rate of decay is caused by a temperature rise in the photoconductor due to power dissipated by the high photocurrents. Fig. 12 shows a similar set of build-up and decay curves for biased ac operation. The decay curves here are almost straight lines, indicating an exponential decay, with about eight seconds required for the output light to fall to one tenth its value. Here again, the curve for the highest input light level, shown as a dashed line, crosses the lower curves due to the temperature rise in the photoconductor.

From the curves of Fig. 12 the time-integrated output light can be obtained for each input light level. Fig. 13 shows the integrated output light corresponding to the different integrated input light values. This curve also has a high slope, indicating a gamma of about 2. The maximum integrated gain is about 100 times, using the yellow electroluminescent input light. With proper spectral match to the photoconductor, an integrated energy gain of about 200 is possible.

#### PICTURE QUALITY

Fig. 14 shows a photograph of the output picture produced on a 12-inch light amplifier with a low-level image projected from behind. In operation, biased ac was used. The photoconductive layer of this amplifier has horizontal grooves spaced 25 mils apart, allowing a picture resolution of about 500 lines. For a given number of photoconductor grooves, the resolution is the same for biased ac and conventional ac. In both cases each phos-

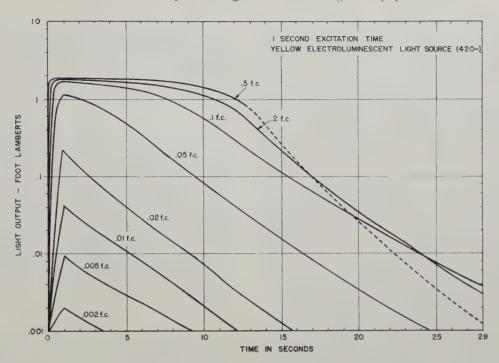


Fig. 12—Decay curves for biased ac operation.

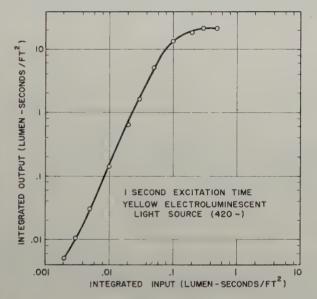


Fig. 13—Input-output characteristic for time-integrated light.

phor element is supplied by photocurrent from the two adjacent photoconductor groove surfaces, which converge at the phosphor element.

#### Conclusion

The high light gains and long persistence of the present amplifier are potentially useful in slow tv and radar applications. In the case of slow tv it is desired to scan a single frame in a period as long as a minute, using low-frequency video information. For viewing the picture, storage is necessary for a frame period or longer. One relatively simple method is to use a cathode-ray tube with a long persistence phosphor. The available light



Fig. 14—Photograph of amplifier output.

during persistence, however, is very low and the image must be viewed in completely darkened surroundings. Utilizing the long decay and integrated energy gain of the amplifier, a much brighter picture can be obtained with long storage by projecting a cathode-ray tube image on the amplifier.

The problem of inadequate light level also occurs with the conventional P-7 radar screen where the decaying target traces require a darkened room for viewing. Here again the light amplifier is potentially useful for producing a bright, long-decay output picture from a projected cathode-ray tube image. Similar to the P-7

phosphor, the light amplifier has build-up properties, so that successive input pulses at short intervals cause an increase in the output light.

The present light amplifier is also sensitive to radiation in the near infrared, extending to about 900 millimicrons. For stationary scenes it can convert a low-level infrared image to a visible picture of much higher level. Alternatively, with a pulsed infrared source, an instantaneous image may be temporarily recorded for direct viewing.

The CdS photoconductor used in the amplifier is also highly sensitive to X rays. The panel can thus directly convert an X-ray image to a visible picture. Until now, the fluoroscope screen has been the primary means for the direct viewing of X-ray images in medical and industrial applications. As is well known, the image on the fluoroscope screen is frequently very dim, particularly in medical applications, requiring a darkened room for viewing and dark adaptation of the observer's eyes for many minutes. Because of the very low light levels and poor image contrast, details can be perceived with difficulty, or not at all. By comparison, the light amplifier with its high gain can convert an X-ray image into a visible picture 100 times brighter than the fluoroscope screen, using the same X-ray levels. The resultant in-

tensified image can be viewed in moderate room light without dark adaptation. In addition, the high gamma of the amplifier greatly enhances the contrast of the output image so that details which might be overlooked on the fluoroscope screen can be easily observed on the amplifier.

With its long decay properties, the amplifier is expected to be of use in industrial applications involving stationary objects and in special medical applications where a temporary photograph or bright image is desired for viewing after the X rays have been cut off.

It is the object of further research effort to increase the gain and also the speed of response of the light amplifier with the ultimate aim of viewing motion. This involves the continuing research on the component materials and also the associated development of improved techniques for using these materials in new amplifier structures.

#### ACKNOWLEDGMENT

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# The Large-Signal Behavior of Crossed-Field Traveling-Wave Devices\*

J. FEINSTEIN†, MEMBER, IRE, AND G. S. KINO†, ASSOCIATE, IRE

Summary-A large-signal theory for the interaction between a slow wave and a beam of electrons traveling in crossed dc electric and magnetic fields is formulated. The adiabatic equations of motion are used, space-charge forces are neglected, but phase focusing by the rf field and loss of the beam at the anode and sole plate are taken into account. The limits of validity of the conventional small-signal theory are obtained, and an analog computer is employed to follow the interaction to power saturation. Results are presented for a forward-wave amplifier, backward-wave amplifier, and backward-wave oscillator. It is shown that for very short lengths the backward-wave amplifier may give superior results to the equivalent forward-wave amplifier but that otherwise greater gain and efficiency can be obtained with a forward-wave amplifier. However, it is shown that there is a mode of operation for a backward-wave tube equivalent to an oscillator started by and then locked to the input signal, a condition unlike anything obtained in the equivalent longitudinal twt. Also, it is shown that in a forward-wave or backward-wave tube, the gain is dependent on the input signal and may increase as the input signal level is increased. However, it is apparent that this

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manuscript received, July 23, 1957. † Bell Telephone Labs., Inc., Murray Hill, N. J. type of device has inherently a low gain, especially when designed for high efficiency. Consequently, some suggestions which have been made for improving this deficiency are examined.

#### Introduction

HE HIGH POWER at high efficiency obtainable from the multicavity magnetron has always made the application of crossed-field electronics to other types of devices seem attractive. However, forward-wave-magnetron amplifiers have not been very successful owing to the low gains usually obtained. In the M-type Carcinotron,¹ on the other hand, the backward-wave oscillator has successfully been applied to crossed-field interaction, although certain experiments indicate that the optimum operating conditions for high efficiency are not usually achieved.

<sup>&</sup>lt;sup>1</sup> R. R. Warnecke, "Some results obtained in the field of ultra high-frequency electron tubes," *Ann. Radioelect.*, vol. 9, pp. 107–136; April, 1954.

Up to the present time, only a small-signal theory of the operation of crossed-field tubes has been available. Since these devices have their main applicability in the large-signal regime, the analysis to be presented below has been developed as an attempt to clarify the situation.

#### STATEMENT OF THE PROBLEM

We shall consider the system of Fig. 1. A narrow sheet beam of electrons enters the rf field at x=0, y=0 and flows initially along the y=0 plane parallel to the direction of propagation of the rf field. It will be assumed that the beam would be under Brillouin flow conditions in the absence of rf field; *i.e.*, the beam would flow along the plane y=0 in the +x direction under the influence of a uniform magnetic field, B, in the z direction, and a uniform electrostatic field,  $E_0$ , in the -y direction. The initial dc velocity of the beam will therefore be  $U_0$  where  $U_0 = E_0/B$ .

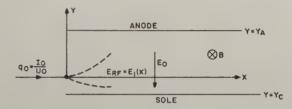


Fig. 1-Model of the magnetron amplifier considered in this paper.

It will be necessary to derive a trajectory equation for the beam under the combined action of rf and dc fields. In order to derive a reasonably simple expression, the following assumptions will be made:

- 1) The phase velocity of the rf field is  $U_0$  and remains uniform along the direction of propagation even under large-signal conditions.
- 2) The influence of space charge on the rf and dc fields may be neglected.
- 3) The gain per wavelength along the propagating circuit is small.
- 4) The influence of the sole plate on the rf field distribution is negligible. However, collection of electrons at the sole plate will be taken into account.
- 5) The "adiabatic" equations of motion may be used, *i.e.*, the acceleration terms in the equations of motion may be neglected so as to obtain essentially an "average" trajectory for an electron.
- 6) For simplicity, the rf circuit loss will be assumed to be negligible. Such an assumption is not vital to the treatment.
- 7) Again for simplicity the phase velocity of the rf fields is taken to be small compared with the velocity of light.
- 8) The rf field strength at y=0 is much smaller in magnitude than the dc field.

Assumptions 3, 4, and 7 make it possible to express the rf fields in terms of a scalar potential of the form

$$V = V_1(x) \sin (\omega t - \beta x) e^{\beta y}$$
 (1)

where  $\beta = \omega/U_0$ ,  $\omega$  is the angular frequency of the wave;  $V_1(x)$  is a quantity proportional to the amplitude of the rf field at any point along the circuit, so that  $|\partial V_1/\partial x| \ll |\beta V_1|$ .

The rf fields may therefore be expressed in the form

$$E_x = E_1(x) \cos (\beta x - \omega t) e^{\beta y} \tag{2}$$

$$E_y = E_1(x) \sin (\beta x - \omega t) e^{\beta y}$$
 (3)

where  $E_1(x) = \beta V_1(x)$ .

The equations of motion of an electron under the action of the combined rf and dc fields may then be written as follows

$$\frac{m}{e}\frac{d^2x}{dt_2} = E_1 \cos(\beta x - \omega t)e^{\beta y} - B\frac{dy}{dt}$$
(4)

$$\frac{m}{e} \frac{d^2y}{dt^2} = E_1 \sin(\beta x - \omega t)e^{\beta y} - E_0 + B \frac{dx}{dt}$$
 (5)

where  $E_1$  is written for  $E_1(x)$ , as it will be henceforth.

It is convenient as well as enlightening to a physical understanding of the electron motion to transform to a system of moving coordinates x', y' moving with a velocity  $U_0 = E_0/B$  in the x direction, and coincident with the stationary system at time t=0. In this case  $x'=x-U_0t$ , and y'=y, so that the equations of motion of an electron in the moving system become

$$\frac{m}{e} \frac{d^2x'}{dt^2} = E_1 \cos \beta x' e^{\beta y'} - B \frac{dy'}{dt}$$
 (6)

$$\frac{m}{e} \frac{d^2y'}{dt^2} = E_1 \sin \beta x' e^{\beta y'} + B \frac{dx'}{dt}$$
 (7)

Finally, it is convenient to express the equations of motion in the moving system in terms of a set of normalized coordinates,  $X = \beta x'$ ,  $Y = \beta y'$ , and  $T = \omega t$ , so that (6) and (7) become

$$\frac{\omega}{\omega_h} \dot{X} = \frac{E_1}{E_0} \cos X e^{\gamma} - \dot{Y} \tag{8}$$

and

$$\frac{\omega}{\omega_h} \ddot{Y} = \frac{E_1}{E_0} \sin X e^Y + X \tag{9}$$

where (·) denotes differentiation with respect to T, and  $\omega_h = eB/m$  is the cyclotron resonance frequency.

It can be seen that if  $\omega/\omega_h\ll 1$ , *i.e.*, if the magnetic field is large, the term on the left-hand side of (8) and (9) may be neglected. However, in most cases of interest  $\omega_h/\omega$  is not a large number but is of order unity. In accordance with assumption 5, we nevertheless neglect the left-hand side of (8) and (9).<sup>2</sup> Under this condition these equations take the very simple form

<sup>&</sup>lt;sup>2</sup> A discussion of the error associated with this approximation is given in Appendix I.

$$\dot{Y} = \frac{E_1}{E_0} \cos X e^{Y} \tag{10}$$

$$\dot{X} = -\frac{E_1}{E_0} \sin X e^{Y}.$$
 (11)

Eq. (10) may be divided by (11) to yield the following differential equation for the electron trajectories

$$\frac{dY}{dX} = -\cot X \tag{12}$$

with the trajectory solution

$$e^Y \sin X = \sin X_0 \tag{13}$$

for an electron entering the rf field at Y=0 with entrance phase,  $X_0$ .

Thus the shape of an electron trajectory in the moving system is independent of the strength of the rf field. However, the time which it takes an individual electron to traverse its path is, of course, dependent on the strength of the rf field. Also, it will be noted that an electron entering at phase,  $X_0$ , so that  $-(\pi/2) < X_0 < \pi/2$ , will travel directly towards the anode. An electron entering the field at phase,  $X_0$ , so that  $(\pi/2) < X_0 < 3\pi/2$ , will initially move in the negative y direction, and ultimately strike the sole plate; or alternatively will reverse its y component of velocity before striking the sole plate, and then ultimately strike the anode.

It will be convenient to know not only the trajectory of an individual electron, but also its position and velocity with respect to normalized time, T, or distance along the circuit, x. These relations may be found by substitution of (13) in (10) and (11) to yield:

$$\dot{X} = -\frac{E_1}{E_0} \sin X_0.$$
 (14)

However, if it is recalled that  $T = \omega t$ ,  $X = \beta x'$ , and  $x = x' + U_0 t$ , then it is possible to write  $\dot{X}$  in the form

$$\dot{X} = \frac{dX}{dx} \frac{dx}{dt} \frac{dt}{dT}$$

$$= \left(U_0 + \frac{dx'}{dt}\right) \frac{1}{\omega} \frac{dX}{dx}$$

$$= \frac{1}{\beta} (1 + \dot{X}) \frac{dX}{dx} .$$
(15)

It is therefore possible to express  $\dot{X}$  directly in terms of dX/dx. However, in order to produce tractable integrals, it is convenient to neglect  $\dot{X}$  compared with unity. This is reasonable, for it can be seen from (14) that only assumption 8,  $(E_1/E_0)\ll 1$ , is involved; this is certainly true for the types of slow wave circuits and beam perveances obtainable in practice. Thus (15) becomes

$$\frac{dX}{dx} = -\frac{\beta E_1}{E_0} \sin X_0$$

which may be integrated to give

$$X = X_0 - \frac{\beta \sin X_0}{E_0} \int_0^x E_1(x) dx.$$
 (16)

It will be convenient to write

$$F = F(x) = \frac{\beta}{E_0} \int_0^x E_1(x) dx$$
 (17)

so that (16) becomes

$$X = X_0 - F \sin X_0. \tag{18}$$

Substitution of (18) in (13) then yields the following expression for the Y coordinate of an electron starting at initial phase  $X_0$ :

$$e^{Y} = \frac{\sin X_{0}}{\sin (X_{0} - F \sin X_{0})}, \tag{19}$$

and it follows from (10) that

$$\dot{Y} = \frac{E_1}{E_0} \sin X_{\theta} \cot (X_0 - F \sin X_0). \tag{20}$$

The position and velocity of an electron entering at arbitrary phase  $X_0$  have now been expressed in terms of the fields existing in the system. It still remains to determine the expression for the field at any point of the circuit due to the motion of the beam. The combination of these two results will then yield the solution for F, and hence the field,  $E_1$ , as a function of distance along the circuit.

Consider the average power dP delivered to the circuit between x and x+dx. We may write

$$dP = \frac{dx}{2\pi} \int_{X_0=0}^{X_0=2\pi} q\bar{v} \cdot \overline{E} \ dX$$
 (21)

where  $\overline{E}$  is the rf field at any point distance x from where the beam enters the circuit,  $q\ dX$  is the charge passing through dx, in the time required for a phase change dX, and the integration is taken over one cycle of rf, or a change in  $2\pi$  of entrance phase.

Eq. (21) may be written in the form

$$dP = \frac{dx}{2\pi} \int_{X_0=0}^{X_0=2\pi} q U_0(E_x + \dot{X}E_x + \dot{Y}E_y) dX.$$
 (22)

However, it may be seen by substitution of (10) and (11) in (22) that the second and third terms of the integrand add to zero, because in the moving system the trajectories are at right angles to the direction of the rf electric field,  $\overline{E}$ . It may also be seen from (2) and (10) that the first term of the integrand may be written in the form  $qU_0\dot{Y}E_0$  to yield the following expression for dP

$$dP = \frac{dx}{2\pi} \int_{X_0=0}^{X_0=2\pi} q U_0 \dot{Y} E_0 dX.$$
 (23)

It may be seen that, as might be expected, (23) is just the expression for the dc power lost over the distance dx. Because of this, it is convenient to write

$$dP = I_{dc} E_0 dx \tag{24}$$

where

$$I_{dc} = \frac{1}{2\pi} \int_{X_0=0}^{X_0=2\pi} q U_0 \dot{Y} dX.$$

But if q is the charge per unit length at a distance x from the entry point of the beam into the circuit, then  $q = q_0 dX_0/dX$ , where  $q_0$  is the charge per unit length entering the circuit, or  $q_0 = I_0/U_0$ . Hence

$$I_{dc} = \frac{I_0}{2\pi} \int_0^{2\pi} \dot{Y} dX_0.$$
 (25)

The substitution of (20) in (25) yields the following expression for  $I_{dc}$ 

$$I_{dc} = \frac{I_0 E_1}{2\pi E_0} \int_0^{2\pi} \sin X_0 \cot (X_0 - F \sin X_0) dX_0.$$
 (26)

It will be convenient to write

$$G(F) = \frac{1}{2\pi} \int_{0}^{2\pi} \sin X_{0} \cot (X_{0} - F \sin X_{0}) dX_{0}, \quad (27)$$

so that (24) becomes

$$\frac{dP}{dx} = I_0 E_1 G(F). \tag{28}$$

Now, at a distance x along the system, the power flow, P, is directly proportional to the square of the amplitude of the rf field at y=0,  $E_1^2$ . Therefore, it is possible to write  $P=E_1^2/2\beta^2K$ , where K is the impedance of the circuit at y=0. It is therefore possible to write (28) in the form

$$E_1 \frac{dE_1}{dx} = \pm K\beta^2 I_0 E_1 G(F)$$

where the + sign is taken for a forward wave, and the - sign for a backward wave. Therefore

$$\frac{dE_1}{dx} = \pm K\beta^2 I_0 G(F). \tag{29}$$

The substitution of (17) in (29) then yields the following differential equation for F from which may be determined the fields at any point of the system.

$$\frac{d^2F}{dx^2} = \pm \frac{K\beta^3 I_0}{E_0} G(F). \tag{30}$$

It is convenient to define a dimensionless gain parameter, D, given by the expression

$$D^{2} = \frac{K\beta I_{0}}{E_{0}} = \frac{\omega}{\omega_{h}} \frac{KI_{0}}{2V_{0}}$$
 (31)

where  $V_{\mathfrak{d}}$  is the dc potential at which the beam enters the system. The differential equation for F then becomes

$$\frac{d^2F}{dx^2} = \pm D^2\beta^2 G(F). \tag{32}$$

#### DISCUSSION OF RESULTS

Analytic Solution—Small Signal Treatment

Eq. (32) is not, in general, soluble analytically due to the nature of G(F). Consequently, it is usually necessary to solve the equation numerically. As a first step, G(F) is found as a function of F. This has been done on an analog computer, and the resultant function is plotted in Fig. 2.

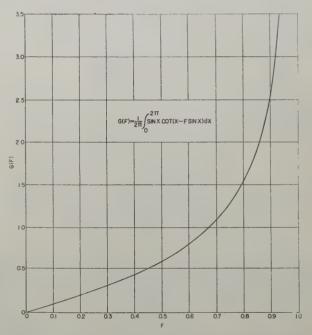


Fig. 2—The parameter  $G(F) = (1/2\pi) \int_0^{2\pi} \sin X \cdot \cot (X - F \sin X) \cdot dX$ . No beam interception is assumed.

However, for small signals, F is small so that it is possible to neglect second order terms in F in (27) and write  $\cot (X_0 - F \sin X_0) \simeq \cot X_0 + F/\sin X_0$ , thus yielding the simple form for G(F),  $G(F) \simeq F$ . It may be seen from Fig. 2 that this expression for G(F) is valid for values of F up to about 0.3, where the error in G(F) is about 10 per cent.

Thus the small-signal approximation will yield (32) in the approximate form

$$\frac{d^2F}{dx^2} = \pm D^2\beta^2F,\tag{33}$$

the sign being positive for a forward-wave system and negative for a backward-wave system.

In the case of a forward-wave amplifier, it will be seen from (17) that the boundary conditions at x = 0 are

$$F(0) = 0$$

$$\left(\frac{dF}{dx}\right)_{x=0} = \frac{\beta E_1(0)}{E_0}$$
(34)

which yields the following solution for (33):

$$F(x) = \frac{E_1(0)}{E_0 D} \sinh \beta Dx \tag{35}$$

and

$$E_1(x) = E_1(0) \cosh \beta Dx. \tag{36}$$

This solution is identical to the small-signal solution given by Pierce<sup>3</sup> under the same conditions.

It is interesting, before proceeding further, to determine the range of validity of the small-signal solution. It has already been determined that the assumption G(F) = F only gives reasonable accuracy for values of F up to about 0.3. Dividing (35) by (36) it will be seen that we may write

$$F(x) = \frac{E_1(x)}{E_0 D} \tanh \beta Dx. \tag{37}$$

Hence the condition that F(x) < 0.3 yields the condition at the end of a tube of length, L:

$$\left[\frac{E_1(L)}{E_0 D}\right]^2 < 0.09 \coth^2 \beta DL.$$
 (38)

By using (31) and the expression for the output power of the tube,  $2P = E_1^2(L)/\beta^2 K$ , we find that

$$P < 0.09I_0V_0\omega_h(\coth\beta DL)^2\omega. \tag{39}$$

However, for a tube of reasonable length,  $\coth \beta DL \simeq 1$ , so that the estimate for the output power for which the small-signal theory is valid becomes

$$P < 0.09 I_0 V_0 \omega_h / \omega \tag{40}$$

provided that the anode and sole plate are sufficiently far from the beam to preclude interception of electrons.

Consider now the solution for a backward-wave amplifier under small-signal conditions. It will be seen from (17) that the boundary conditions on (33) are

$$F(0) = 0$$

$$\left(\frac{dF}{dx}\right)_{r=L} = \frac{\beta E_1(L)}{E_0}$$

where L is the length of the amplifier.

Eq. (33) then yields the following solution

$$F(x) = \frac{E_1(L)}{E_0 D} \frac{\sin \beta Dx}{\cos \beta DL}$$

$$E_1(x) = E_1(L) \frac{\cos \beta Dx}{\cos \beta DL}.$$
(41)

For the usual oscillator case  $E_1(L) = 0$ , so that for oscillation there is the additional condition  $\beta DL = (2n+1)\pi/2$ . This solution and condition for oscillation agrees with the usual small-signal analysis, provided that it is assumed that the beam velocity on entry into the system is the same as the phase velocity of the rf along the circuit.<sup>4</sup>

Large Signal Solution

While it is possible to reduce (32) to quadratures even in the general case, the numerical form in which G(F) is available for large F makes the differential analyzer an ideal tool for the solution of the equation.

However, before proceeding to obtain a solution of (32), it is necessary to modify the form of G(F) to take account of the collection of electrons at the anode and the sole plate, as this effect is most important at large-signal levels. To make this modification, the limits of (27) must be changed so that Y can never exceed  $\beta y_a$  or be less than  $\beta y_c$ , where  $y = y_a$  and  $y = y_c$  are the positions of the anode and sole plate, respectively.

To find the correct limits on  $X_0$  as a function of F, the anode and cathode positions are inserted in (19) to give

$$e^{\beta y_a} = \frac{\sin X_0}{\sin (X_0 - F \sin X_0)} \tag{42}$$

for one limit, and

$$e^{\beta \mathbf{y}_c} = \frac{\sin X_0}{\sin (X_0 - F \sin X_0)} \tag{43}$$

for the other limit.

The parameters  $\beta y_a = 3$ , and  $\beta y_c = -0.5$  have been chosen for the model to be discussed. In this case, (42) may be approximated by

$$\frac{X_0}{\sin X_0} \ge F + 0.05. \tag{44}$$

Thus the zero limit of integration is unaffected until F reaches 0.95 with this anode position; from (43) it can be seen that the first electron strikes the sole plate at F=0.65. The new form of the G(F) curve with these electrode spacings is shown in Fig. 3 and is the one that will be used henceforth. It will be seen that G(F) does not now become infinite at F=1, but reaches a maximum in the region of F=0.95 where electrons bunched around the position of stable phase are collected by the anode. At F=4.6, the upper and lower limits have coalesced signifying that all of the beam has been collected either at the anode or the cathode.

The complete solution for a forward-wave amplifier using the G(F) of Fig. 3 has been carried out on an ana-

<sup>&</sup>lt;sup>3</sup> J. R. Pierce, "Traveling Wave Tubes," D. Van Nostrand Co., Inc., New York, N. Y., ch. 15; 1950.

<sup>&</sup>lt;sup>4</sup> R. Warnecke, P. Guenard, and O. Doehler, "Fundamental phenomena in traveling wave tubes," *Onde Elect.*, vol. 34, pp. 323-328; April, 1954.

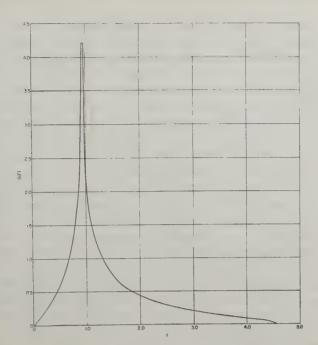


Fig. 3—G(F) for integration limits corrected for finite electrode spacings:  $\beta Y_a = 3$ ,  $\beta Y_c = -\frac{1}{2}$ .

log computer. The results of this computation are given in Fig. 4 and Fig. 5; F and  $E_1/E_0D$  are respectively plotted against DN, N being the number of wavelengths along the tube. It will be seen that the rate of growth of the signal along the tube is initially small, increasing as part of the beam approaches the anode and enters a strong rf field region. In the region where F approaches 0.95, the rate of growth of the signal approaches its maximum value, and then, as the beam is gradually collected at the anode, the rate of growth decreases until the output becomes constant when F > 4.6. At this point, the maximum possible output power which could be delivered to the load is the sum of the input rf power and the dc power expended in moving the beam from its original position to hit the anode. If the anode potential is V, the rf power supplied by the tube will be somewhat less than  $(V-V_0)I_0$  due to the loss of a certain portion of the beam at the sole plate and of the rf energy dissipated by these electrons.

It should be noted that the theory indicates one decided difference in the operation of this type of tube and its equivalent longitudinal twt. This difference is that if operation is well below saturation level, the gain may increase as the input signal level is increased. Consider, for instance, the gain in a tube with DN = 0.35: it will be seen from Fig. 4 that for an input  $E_1(0) = 0.04 E_0 D$ ,  $E_1(L) = 0.13 E_0 D$ , so that the power gain of the tube is  $[(0.13)^2 - (0.04)^2]/(0.04)^2$  or a gain of 9.56. However, for an input  $E_1(0) = 0.2 E_0 D$ , the output  $E_1(L) = 1.24 E_0 D$ , so that the power gain is 31. Thus, with larger input the tube gives larger gain; the reason being, of course, that at large-signal levels the beam moves nearer the anode circuit and hence the effective circuit imped-

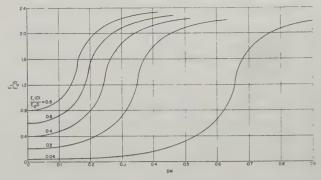


Fig. 4—The amplitude of the rf field,  $E_1$ , of a forward-wave amplifier as a function of position along the circuit measured in wavelengths, N, for the electrode spacings of Fig. 3. The parameter D is proportional to the square root of the ratio of circuit to beam impedance, as defined in the text.

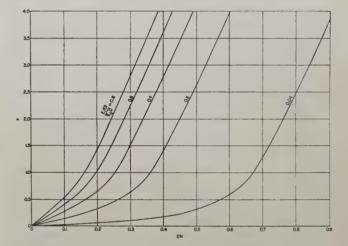


Fig. 5—The variation of F along the circuit for the case of Fig. 4.

ance at the beam is increased. But it will be apparent that this trend does not continue indefinitely, for when  $E_1(0) = 0.8$  the power gain is only 7.27 and would decrease still further for larger input signals due to collection of a sizable portion of the beam at the anode within the length of the tube.

Consider, now, the solutions obtained on the analog computer for the operation of a backward-wave oscillator, the G(F) curve in Fig. 3 being used as before. The tube is assumed to be terminated at x=L and the boundary condition  $E_1(L)=0$  has been taken as in the small-signal case. The resultant solutions for  $E_1/E_0D$  and F are plotted against DN in Fig. 6 and Fig. 7. For any particular curve of Fig. 6 the abscissa for  $E_1=0$  corresponds to the length of the tube, and the ordinate at DN=0 corresponds to the field at the output of a tube of this length, the square of the ordinate being proportional to the output power of the tube.

It will be remembered that (41) implies that small-signal oscillation takes place when  $\beta DL = \pi/2$  or DN = 0.25, though it should always be possible to obtain oscillation for DN > 0.25. The large-signal theory, as can be seen from Fig. 6 shows that DN must be considerably greater than 0.25 to obtain the full saturated output power; for instance, when the tube length corresponds

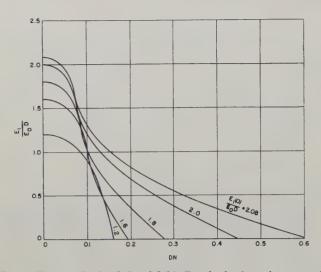


Fig. 6—The amplitude of the rf field,  $E_1$ , of a backward-wave oscillator as a function of position along the circuit for the electrode spacings of Fig. 3.

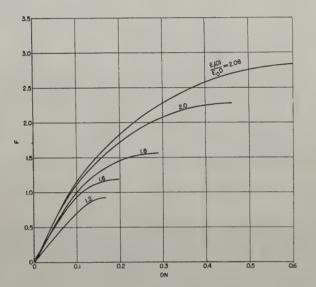


Fig. 7—The variation of F along the circuit for the case of Fig. 6.

to DN=0.28, the output power is  $(1.8)^2$  units or 3.24 units, while when the tube length DN=0.6, the output power is  $(2.08)^2$  units or 4.32 units.

One important implication of the theory which points out the difference between this type of tube and the corresponding O-type Carcinotron is that the curves of Fig. 6 for DN < 0.25 imply that it is possible for oscillation to take place for a tube length DN < 0.25, because at large-signal levels the beam moves closer to the anode over a portion of its length, and the corresponding rf impedance of the circuit at the beam is therefore higher than at the position y=0. However, it would not be expected that this type of oscillation would be selfstarting, as the tube would not oscillate at small-signal levels, i.e., with only noise input to start it for a tube length DN < 0.25. Thus a type of hysteresis effect is implied: no initial oscillation but persistence of oscillation if a large enough input signal at x = L is applied and then removed.

However, for full efficiency as an oscillator, it can be of help to apply an input signal at x = L. Fig. 8 and Fig. 9 show the difference in the situation, as obtained on the analog computer, when an input signal is applied at x = L. As in Fig. 6, the ordinate of Fig. 8 at x = 0 gives the output power of the tube. Now consider a tube length DN = 0.28. From Fig. 6 the output power with zero input signal is (1.8)2 units or 3.24 units. But it may be seen from the lowest curve of Fig. 8 that if an input power of  $(0.83)^2 = 0.69$  is applied to a tube of the same length the output power at x=0 will be  $(2.2)^2$  or 4.84units; thus the rf power contribution of the tube is 4.84 -0.69 = 4.15 units or almost a 30 per cent increase in output power. Thus if the tube is too short to obtain maximum saturated output power, the theory implies that substantially the full output power may be obtained by the application of an input signal. This effect arises again because the application of an input signal serves to bring the beam up to the anode quicker and thus makes the effective DN of the oscillator larger than for a self-excited oscillator.

The hysteresis effect that has already been noted is also apparent from the curves of Fig. 8. Consider, for instance, a tube of length DN = 0.192: from the lowest curve of Fig. 8 an input of (1.03)2 or 1.06 units would give an output of (2.2)2 or 4.84 units, the contributed power of the tube being 3.78 units. If this input is removed, the tube will still remain oscillating with an output of (1.6)2 or 2.56 units. Thus, in this case the rf output contributed by the tube is increased by over 50 per cent when an input signal is present, but the tube would not oscillate if the input signal had never been applied. However, if the original input signal applied had been small enough, this signal would have been amplified and the output of the tube would not have persisted after the input signal had been removed. This particular condition has not been plotted, but of course the possible gain in such a case could be determined from the theory.

#### EVALUATION OF CROSSED-FIELD DEVICES

It will be seen from the curves of Fig. 4 that for a forward-wave amplifier there is no apparent limit to the possible gain obtainable for saturation output, provided that there is no restriction on the length of the tube. However, length is restricted not only by considerations of physical size but also by the difficulty encountered in practice of maintaining a focused electron beam over a great length in an M-type device. The backward-wave amplifier, on the other hand, will not yield large gain at optimum efficiency. Thus, in order to prevent persistence of oscillation after removal of the input signal with a tube of length DN = 0.192 it would be necessary to use an input signal that would yield an output less than the output of the tube when oscillating, i.e.,  $(1.6)^2$  or 2.56units, the maximum possible output which the tube is capable of yielding being greater than (2.08)2 or 4.28 units. Thus the backward-wave structure, when used as

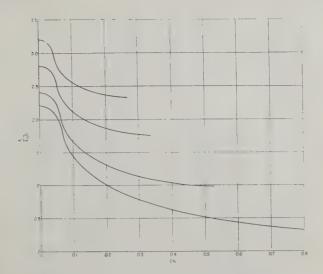


Fig. 8—The amplitude of the rf field of a backward wave amplifier as a function of position along the circuit for the electrode spacings of Fig. 3.

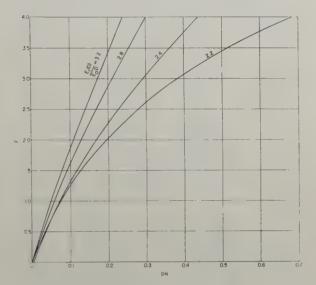


Fig. 9—The variation of F along the circuit for the case of Fig. 8.

an amplifier rather than a locked oscillator can only give very poor efficiency.

Now let us compare a backward-wave amplifier used as a locked oscillator of length DN=0.25 with the corresponding forward-wave amplifier of length DN = 0.25. It will be seen from the lowest curve of Fig. 8 that an input of  $E_1 = 0.88 E_0D$  at the point DN = 0.25 will give an output of  $E_1 = 2.2$   $E_0D$ , so with an input power of  $(0.88)^2 = 0.775$  units the output contributed by the tube is  $(2.2)^2 - 0.775 = 4.07$  units, yielding a gain of 5.26 or 7.2 db. Likewise, it will be seen from the upper curve of Fig. 4 that for a forward-wave tube an input of  $E_1 = 0.8$  $E_0D$  or 0.64 units yields an output of  $E_1=2.13$   $E_0D$  at DN = 0.25, or an output power of 4.54 units, the contributed power of the tube being 3.90 units, and the gain being (3.90/.64) = 6.1 or 7.86 db. Thus the equivalent tubes give virtually the same gain and output for a length of DN = 0.25, the difference being that the backward-wave tube would keep on oscillating after the input signal had been removed. The gain obtainable at good efficiencies from a backward-wave tube are likely to be less than this figure, unless possibly it could be made sufficiently long to be a free running oscillator, yet still be capable of being locked by a small input signal. However, it would seem that the only possible way of obtaining a true amplifier of large gain and good efficiency would be to use a forward-wave circuit and make the tube sufficiently long to fulfill the requirement of high gain.

An alternative method for obtaining higher gain without an increase in physical length might be to move a portion of the anode circuit closer to the beam at entrance, thereby obtaining higher impedance in this region. The dc potential of this portion of the anode would be lowered in accordance with its new position so as to leave the dc electric field unaltered. Electronic efficiency would not be sacrificed since the curves indicate that few electrons reach the anode during the initial interaction. Practical difficulties would arise here in keeping the dc field lines uniform in the transition region between the two anode heights.

Another suggestion calls for the introduction of an rf field at the cathode, or sole electrode in the entrance region. It is well-known<sup>3</sup> that such a field cannot yield gain since the unfavorably phased electrons, which acquire energy from the rf field, move into regions of stronger field (toward the cathode), while those in proper phase to deliver energy to the field move farther from the circuit. Nevertheless it was hoped that a strong premodulation could be effected by such an input circuit as a result of the proximity of the beam to the cathode. The analysis indicates, however, that to first order, no modulation is produced. Physically this result arises from the cancellation of the v scalloping effect by a density modulation which bunches electrons into the depressed portion of the scallops. For greater amounts of modulation a net effect does appear, but the magnitude of the ac produced in the beam under optimum conditions differs by only a factor of about two from its value for the same length of circuit placed at the anode. Thus it would appear that a cathode input circuit cannot contribute materially toward raising the gain of a magnetron amplifier. The calculations indicate that it may be of value in quickly removing the unfavorably phased electrons, reducing the anode circuit length required for good efficiency. In this connection it should be noted that the use of a reentrant beam would also make possible operation at high efficiency with anode lengths corresponding to F=1.5, rather than the F = 4.6 found necessary for the collection of all electrons. The uncollected half of the beam would then simply be recirculated.

In the case of backward-wave interaction, the strong rf field present at the beam entrance position reduces the physical distance required to effect a given degree of beam modulation. However, as power saturation is approached, this effect becomes relatively unimportant. An additional advantage inherent to this mode of operation lies in the greater control over the beam achieved at entrance, possibly preventing space charge and cycloid effects, neglected in our idealized model, from exerting a deleterious effect. The weak rf field near the collector end for normal oscillator operation, however, makes a long circuit necessary if one wishes to obtain full saturated power from this device. The effect of a strong input signal at the collector end in overcoming this limitation has already been discussed. In the absence of such a signal, a reentrant beam would at least prevent a reduction in efficiency from accompanying the reduced power output.

Finally, the use of a continuously emitting cathode rather than the single beam dealt with here has been proposed as a means of increasing the perveance of these devices. Such a system would combine some features of the magnetron oscillator with the uniform beam, traveling-wave analysis given here. If such a device could indeed be controlled it might lead to greatly enhanced power outputs and efficiencies. Since the additional current is fed into the system in regions of strong rf fields, however, it would not necessarily ameliorate the low gain problem.

#### APPENDIX

Figs. 10-13 give a comparison of the electron trajectories obtained from (8) and (9) for various values of  $\omega/\omega_h$  and for two entrance conditions into the rf field. The dependence of  $E_1/E_0$  on distance X has been taken from typical solutions for the forward and backward wave cases given respectively on Fig. 4 and Fig. 6. The parameter D has been chosen as 0.1, a case of rather rapid build-up, and therefore one which furnishes a severe test of the adiabatic approximation. The  $\omega/\omega_h=0$ curves are of course those obtained with this approximation. The two sets of initial conditions specified for the nonzero values of  $\omega/\omega_h$ ,  $\dot{X}(0) = \ddot{Y}(0) = 0$ , and  $\dot{X}(0) = 1$ ,  $\dot{Y}(0) = 0$ , represent an adiabatic entrance into the rf field produced by fringing effects, and a sharp cut-off of rf field at X=0, respectively. In general, one would expect the curves for adiabatic entrance at the lowest value of  $\omega/\omega_h$  to agree best with the approximation used in this paper. While it does appear to be the case that the sharp cut-off type of entrance condition does give rise to more cycloidal looping, the mean trajectories agree about equally well with those for  $\omega/\omega_h=0$ . A qualitative assessment of the effect of the trajectory departures upon the curves of Figs. 4 and Fig. 6 may be obtained by noting that the energy delivered to the circuit by an electron depends only upon its Y displacement. Thus a lateral displacement of a trajectory from its true position results in a corresponding change in the X position along the circuit at which the induced energy appears. If the displacement for many trajecto-

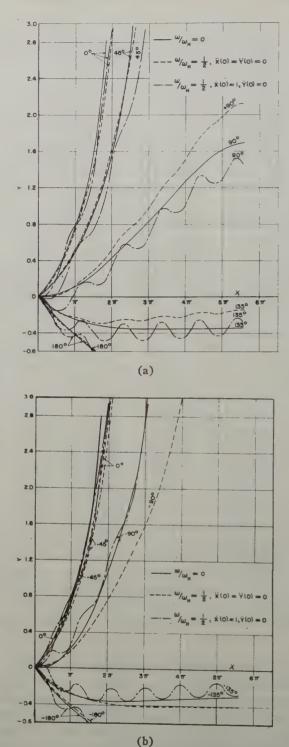


Fig. 10—Comparison of trajectories for the backward wave oscillator case. Trajectories shown are for an rf field variation specified by the curve  $E_1(0)/E_0D=1.8$  on Fig. 6. The entrance phase,  $X_0$ , is specified on each trajectory.

ries are random about the assumed  $(\omega/\omega_h=0)$  position then the final curves for field strength  $(E_1/E_0)$  vs circuit distance would be expected to continue to hold. If, as appears more likely, there is a net displacement of the trajectories [see e.g., 0° and 45° on Fig. 11(a)], then the shape of the circuit field curve would be affected within a lateral distance of the order of the trajectory displace-

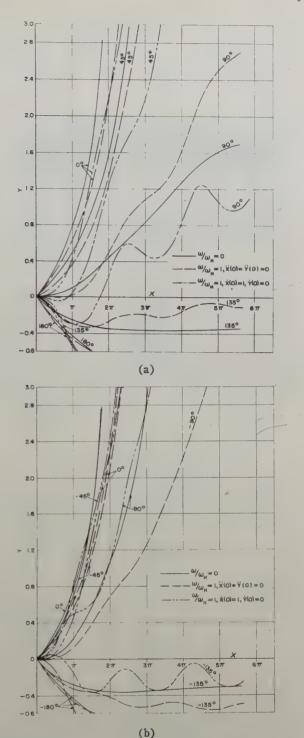


Fig. 11—Comparison of trajectories for the same case as Fig. 10, but with  $\omega/\omega_h=1$ .

ment. For trajectories which do not reach the anode within the tube length [see, e.g., 90° on Fig. 11(a)], there can be a serious error in the extracted energy. Note, however, that the assumed trajectory in this last case lies between those obtained with the two entrance conditions.

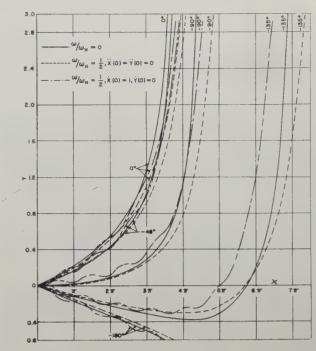


Fig. 12—Comparison of trajectories for the forward-wave amplifier case. Trajectories shown are for an rf field variation specified by the curve  $E_1(0)/E_0D=0.6$  on Fig. 4.

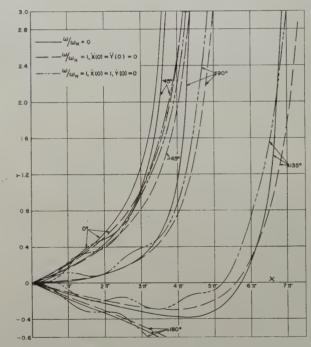


Fig. 13—Comparison of trajectories for the same case as Fig. 12, but with  $\omega/\omega_h=1$ .

#### ACKNOWLEDGMENT

We wish to express our thanks to Mrs. L. R. Lee of the Mathematics Department, Bell Telephone Laboratories, for her work in computing the numerical solutions.



### A Versatile Multiport Biconical Antenna\*

R. C. HONEYT, ASSOCIATE, IRE, AND E. M. T. JONEST, SENIOR MEMBER, IRE

Summary-This paper describes a multiport, biconical antenna that can be used as a wide-band direction finder or multiplexer. When the antenna is used for reception, incident plane waves excite in the feeding coaxial line both the TEM mode and the orthogonal TE11 mode whose azimuthal orientation depends on the direction of arrival of the signal. Directional information can be obtained by measuring the sum of these two modes at four fixed detectors arranged at 90-degree intervals around the coaxial lines. Alternatively, the linearly-polarized TE11 mode can be resolved, with appropriate circuitry, into right- and left-hand circularly-polarized TE11 modes. Then directional information can be obtained by measuring the phase difference between either of the circularly-polarized modes and the TEM mode. This latter form of direction finder is well suited to multiplexing applications, because each of its three ports is well isolated from the others. Furthermore, this antenna has the unique property that a signal fed into any one of these three ports will cause the antenna to radiate omnidirectionally in azimuth. A waveguide version of this antenna has been built and tested and found to operate well over the frequency range of 8.2 to 12.4 kmc.

#### GENERAL DESCRIPTION

THE novel multiport antenna, described here, has interesting applications to wide-band direction finding and multiplexing. Basically, the antenna uses various orthogonal modes with differing azimuthal properties to yield directional information, and uses the decoupling among these various modes to yield the isolation required for multiplexing. 1-3

As shown in Figs. 1 and 2, the antenna consists of a biconical radiator which tapers into a coaxial line at its center. A plane wave incident on the antenna excites a large number of propagating radial-line modes in the antenna, which are transformed into coaxial-line modes by the flared section between the biconical antenna and the uniform coaxial line. This coaxial line is only large enough to propagate the TEM and the TE<sub>11</sub> modes, all others being cut off. Thus the TEM radial-line mode is transformed into the TEM coaxial line mode, and the TE<sub>10</sub> radial-line mode is transformed into the TE<sub>11</sub> coaxial-line mode.

The coaxial line is divided into four waveguide channels, located symmetrically about the axis of the coaxial line. A wide-band (at least 1.5 to 1 frequency range) instantaneous direction finder can be constructed by connecting four well-matched square-law detectors to these

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† Stanford Res. Inst., Menlo Park, Calif.

† Stanford Res. Inst., Menlo Park, Calif.

† The Staff of the Radio Res. Lab., Harvard Univ., "Very High Frequency Techniques," McGraw-Hill Book Co., Inc., New York, N. Y., Vol. I, p. 236; 1947.

† Leonard Hatkin of SCEL has considered instantaneous direction for this type in unpublished memorands.

\*Identify the stype in unpublished memoranda.

\*O. M. Woodward, Jr. and J. J. Gibson, "The omniguide antenna—an omnidirectional waveguide array for uhf-television broadcasting," RCA Rev., vol. 17, pp. 13–36; March, 1956.



Fig. 1-Instantaneous video direction-finding antenna.

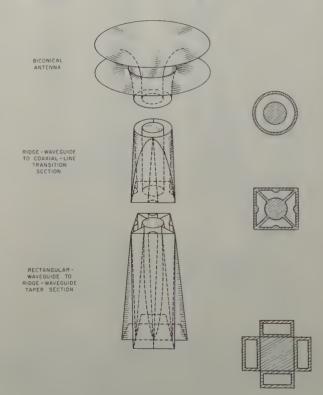


Fig. 2—Video direction-finder circuitry.

four waveguide channels. The direction of arrival of a received signal is inferred from the relative amplitudes of the sums of the TEM and the TE11 coaxial-line modes as measured by these four detectors.

It is possible, by replacing the four detectors with additional waveguide circuitry, to separate the linearly polarized TE<sub>11</sub> coaxial-line mode into two circularly-polarized components rotating in opposite directions. In this way, three orthogonal modes—right- and left-hand circularly-polarized TE<sub>11</sub> coaxial-line modes and the TEM mode—can be brought out to three separate ports. The direction of arrival of a received signal may be determined with no ambiguity by measuring the phase difference between the TEM mode and either of the circularly-polarized modes. Furthermore, since the modes are orthogonal, and since each radiates essentially the same omnidirectional power pattern, this antenna can be used as a three-terminal-pair omnidirectional multiplexing antenna over at least a 1.5 to 1 frequency band.

The antenna systems described here operate with vertical polarization. There are various ways, however, by which the polarization may be modified. For example, metal vanes oriented at 45° from the axis and mounted around the circumference of the aperture will cause the radiated signal to be linearly polarized at approximately 45° if the vanes are less than a half-wavelength apart, and to be elliptically or circularly polarized if the vanes are over a half-wavelength apart. The accuracy of the various directing-finding systems or the isolation of the multiplexing system should not be impaired by this modification.

### Application to Omnidirectional Wide-Band Video Direction-Finding

This antenna, described above and shown in Figs. 1 and 2, can instantaneously determine the direction of arrival of a received signal from any azimuth direction over a 1.5 to 1 frequency band. It requires four square-law detectors whose reflection coefficients and sensitivities are as nearly alike as possible over the frequency band. These detectors measure the sum of the TEM and the  $TE_{11}$  coaxial-line modes. By taking the difference in the signals from opposite pairs of detectors, two output signals are obtained:

 $E_v = C \sin \phi \cos \delta$ 

and

$$E_h = C \cos \phi \cos \delta$$
,

where  $\phi$  is the angular bearing of the received signal and  $\delta$  is the net phase difference between the TEM mode and the TE<sub>10</sub> radial-line and TE<sub>11</sub> coaxial-line modes due to the different phase velocities in the antenna and coaxial line. If these two signals are applied to the vertical and horizontal plates of an oscilloscope, the angular position of the radial trace is a direct measure of the bearing angle.

Since both  $E_{\nu}$  and  $E_{\hbar}$  are proportional to  $\cos \delta$ , the video output of the difference signals goes to zero whenever  $\cos \delta$  goes to zero. It is desirable, therefore, to maintain  $|\cos \delta|$  as near unity as possible throughout the frequency band.

Because of the various lengths of nonuniform transmission line in the biconical antenna, in the flared co-

axial feed, and in the transition section from coaxial-line to ridge-waveguide, it is difficult to estimate  $\delta$  accurately. In the first version of this direction finder, which was built to operate from 8.2 to 12.4 kmc,  $\delta = 270^{\circ}$  at 9.33 kmc, and extrapolation of the measured values of  $\delta$  showed that  $\delta = 360^{\circ}$  and 180° at 7.8 and 13.2 kmc, respectively. Thus, cos  $\delta$  was zero at 9.33 kmc, and output signals  $E_v$  and  $E_h$  dropped to zero at this frequency.

This direction finder was then modified by removing one inch of the uniform coaxial-line connecting the antenna to the ridge-waveguide transition section. This moved the point at which  $\delta = 180^{\circ}$  to 9.6 kmc, with  $\delta = 220^{\circ}$  and 147° at 8.2 and 12.4 kmc, respectively. Hence, with this change the output drops by only 2.3 and 1.5 db, respectively, at the two ends of the band. However, the concurrent reduction of the cutoff attenuation of the higher-order modes, particularly the  $TE_{21}$  coaxial-line modes, seriously increased the bearing errors at the high-frequency end of the band. A redesign of the ridge-guide to coaxial-line transition section should increase the attenuation of the  $TE_{21}$  mode and reduce the bearing errors.

The bearing errors for the direction finder were measured in the following manner. At each test frequency, opposite pairs of detectors were matched and their sensitivities equalized. The difference in the outputs from opposite pairs of detectors was recorded as a function of azimuth angle as the antenna was rotated on the antenna pattern range. Such a difference pattern is shown in Fig. 3. For a given true bearing,  $\phi$ , the apparent bearing is given by

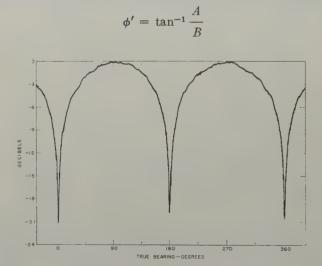


Fig. 3—Response of one pair of detectors on the video direction finder at 8.3 kmc.

where A is the amplitude of the sinusoidal curve from one pair of detectors at  $\phi$ , and B is the amplitude of the cosinusoidal curve from the other pair at  $\phi$ . The indicated bearing would be  $\phi'$  if the two signals were applied to the horizontal and vertical plates of an oscilloscope that introduced no additional errors of its own. The difference between  $\phi$  and  $\phi'$  is the bearing error.

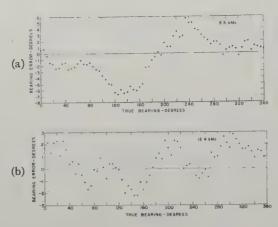


Fig. 4—Bearing errors for original video direction-finder.

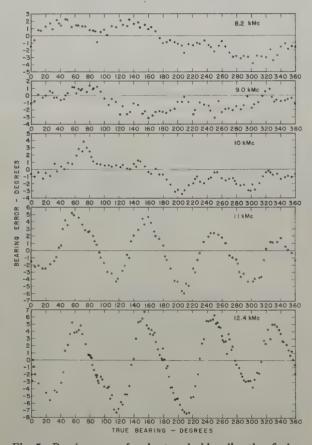


Fig. 5—Bearing errors for shortened video direction-finder.

The bearing errors for the first version of the direction finder at 8.3 and 12.4 kmc are shown in Fig. 4. At 8.3 kmc, the maximum bearing error is 6° from the mean, while at 12.4 kmc the maximum error is 2.2° from the mean. The bearing errors for the same direction finder with one inch less of coaxial line are shown in Fig. 5 for five frequencies in the band 8.2 to 12.4 kmc. It can be seen from the figure how the presence of the  $TE_{21}$  coaxial-line mode increases the errors as the frequency is increased. At 8.2 kmc, the maximum error is  $\pm 3^{\circ}$ , while at 12.4 kmc it has increased to  $\pm 7^{\circ}$ . The 90-degree period of the cycle variation of the bearing errors indicates the presence of the  $TE_{21}$  mode.

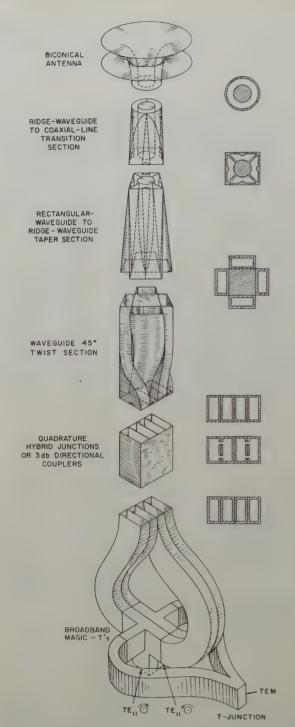


Fig. 6—Wide-band multiplexing and direction-finding antenna.

The bearing errors of a direction finder of this type can arise from five sources:

- 1) Mechanical asymmetries in the antenna, the antenna's environment, and the transition section;
- Unequal current sensitivities among the four detectors;
- 3) Mismatched detectors;
- 4) Inadequate attenuation of the higher-order modes;
- 5) Deviation from square-law detector response.



Fig. 7—Wide-band waveguide circuitry.

The first source of error has been minimized by employing precision construction techniques which result in a high degree of symmetry among the four channels. It is felt that asymmetries contribute only slightly to the residual errors of the present system. The second source of errors, unequal current sensitivities among the four detectors, is treated in Appendix II-A, where it is shown that the errors will be less than  $\pm 2^{\circ}$  if the video output signals from the detectors are within  $\pm \frac{1}{2}$  db of each other for equal rf input signals. The third source of errors, mismatched detectors, is treated in Appendix II-B, where it is shown that the errors will be less than  $\pm 2^{\circ}$ if a single detector has an input vswr less than 1.3. If all detectors have identical reflection coefficients, the errors cancel out. The fourth source of errors, inadequate attenuation of higher-order modes, is treated in Appendix II-C, where it is shown that the below cutoff attenuation of the TE21 mode must be greater than 30 db to keep the bearing errors below  $\pm 2^{\circ}$ .

The measured bearing errors arose principally from the first and fourth sources, since the errors introduced by the remaining sources were made quite small.



Fig. 8—Wide-band multiplexing antenna on pattern range.

#### Application to Omnidirectional Wide-Band Multiplexing and Direction-Finding

This antenna utilizes the same components as the video direction finder, except that the detectors are replaced by the additional waveguide circuitry shown in Fig. 6. A photograph of this additional circuitry is shown in Fig. 7, while the complete assembly mounted on the antenna pattern range for tests is shown in Fig. 8. This waveguide circuitry is designed to bring the TEM mode out one port, and to separate the linearly polarized TE<sub>11</sub> coaxial-line mode into its two equal, orthogonal, circularly-polarized components and bring them out two additional ports. These two components rotate in opposite directions at the rf frequency and have amplitudes of one-half the amplitude of the linearly-polarized mode. Furthermore, since the power received by the linearly-polarized TE<sub>11</sub> coaxial-line mode is twice that received by the TEM mode (see Appendix I), the power associated with each of the right- and lefthand circularly-polarized components is equal to that of the TEM mode.

A signal fed into one of the TE<sub>11</sub> ports will excite a

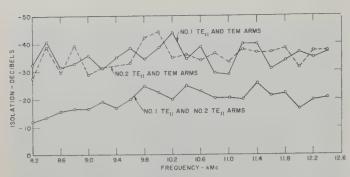


Fig. 9—Isolation between various pairs of ports of the multiplexing antenna.

circularly-polarized  $TE_{11}$  mode in the coaxial line, which is transformed to a spiral-phase  $TE_{10}$  radial-line mode in the biconical antenna. The radiation pattern of the  $TE_{10}$  radial-line mode is a figure-eight which rotates at the rf frequency. This rotating field distribution is termed a "spiral-phase" mode, since a line of constant phase in the far-field radiation pattern forms a spiral.

The manner in which the circuitry shown in Fig. 6 separates the three orthogonal modes in the coaxial line can be understood by considering the transmitting case. Fig. 6 shows three waveguide ports at the bottom of the figure, one coupling to the TEM mode, and two coupling to the two circularly-polarized modes. A signal fed into the TEM port will excite all four waveguides at the top of the figure in phase and hence excite only the TEM mode in the coaxial line. On the other hand, a signal fed into either TE<sub>11</sub> port will also divide equally among the four waveguides; however, the 180-degree phase shifts introduced by the Magic-T's and the 90degree phase shifts introduced by the 3-db directional couplers cause the four waveguides to have a progressive 90-degree phase difference around the periphery of the coaxial line. Therefore, a signal fed into either TE<sub>11</sub> terminal excites a circularly-polarized TE11 mode in the coaxial line. Additional study has shown that all three terminals are isolated from each other.

An analysis of the cross-coupling between ports shows that it is not necessary that the 3-db couplers split the power exactly, only that they be identical. For 0.1-db difference between the two couplers, isolations of at least 45 to 50 db could be obtained if the remaining components were perfect. The best available broad-band Magic-T's provide minimum isolations of only 35 db over the waveguide band, hence they are the principal limiting factor. The isolation between the two TE<sub>11</sub> ports is directly affected by any symmetrical mismatch in the coaxial line or antenna, since such a reflection returns directly out the opposite channel.

As the multiplexer, then, this antenna has the following characteristics.

- 1) Three isolated input channels producing essentially the same far-field power radiation patterns.
- 2) Coverage over at least a 1.5 to 1 frequency band—in this case, 8.2 to 12.4 kmc.

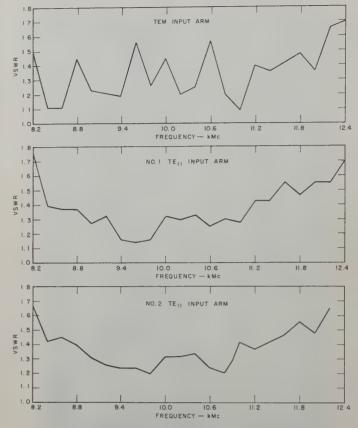


Fig. 10—VSWR vs frequency looking into the three ports of the multiplexing antenna.

- 3) Fairly high isolation between the TEM port and either TE<sub>11</sub> port—averaging between 30 and 40 db over the band with presently available components (see Fig. 9).
- 4) Somewhat less isolation between the two TE<sub>11</sub> ports—averaging around 20 db, but dropping to 12 db at 8.2 kmc (see Fig. 9).
- 5) Reasonably good match looking into any of the ports—the vswr averaging around 1.35, but never above 1.70—again limited by the performance of presently available broad-band Magic-T's (see Fig. 10).

To use this same antenna as a direction finder, it is necessary to measure the phase difference between the TEM mode and either spiral-phase TE10 radial-line mode, since this phase difference is linearly related to the azimuth angle at a given frequency. Signals at different frequencies coming from the same direction appear to have different bearings because the electrical lengths of the antenna and associated coaxial line are shorter for the TE10 and TE11 modes than for the TEM mode. Because the undesired phase difference between these modes depends only on the frequency of the received signal, it is possible to compensate accurately for this difference by ganging an rf or IF phase-correcting element with the local-oscillator frequency control feeding the mixers on each output port. It is also possible to compensate for this difference by inserting a phaseequalizing network in one of the waveguide channels after the various modes have been separated.

Some of the details involved in the construction and testing of the various components for these direction-finding and multiplexing antennas are given in Appendix III.

#### APPENDIX I

#### A. Analysis of Operation of Video Direction Finder

The video system measures the direction of arrival of a received signal by comparing the amplitudes of the signals received from each of the four waveguides connected to the coaxial line. Ideally, a signal of angular frequency,  $\omega$ , incident on the biconical antenna from an azimuth direction,  $\phi$ , will excite signals in the four waveguides having amplitudes proportional to the sum of the amplitudes of the radial-line TEM and TE<sub>10</sub> modes. Specifically, the signals in the four waveguides will be

$$E_1 = A \sin \omega t + B \sin \phi \sin (\omega t - \delta)$$

$$E_2 = A \sin \omega t + B \cos \phi \sin (\omega t - \delta)$$

$$E_3 = A \sin \omega t - B \sin \phi \sin (\omega t - \delta)$$
(1)

and

$$E_4 = A \sin \omega t - B \cos \phi \sin (\omega t - \delta),$$

where

- A = E-field amplitude induced in one waveguide by the TEM mode:
- B = E-field amplitude induced in one waveguide by the TE<sub>10</sub> radial-line mode;
- $\delta$  = the amount that the phase of the signal induced by the TEM mode leads that of the signal induced by the TE<sub>10</sub> mode.

Separate detection of each of these signals by identical square-law detectors produces video signals of the following relative amplitudes:

$$E_{1d} = A^{2} + 2AB \sin \phi \cos \delta + B^{2} \sin^{2} \phi$$

$$E_{2d} = A^{2} + 2AB \cos \phi \cos \delta + B^{2} \cos^{2} \phi$$

$$E_{3d} = A^{2} - 2AB \sin \phi \cos \delta + B^{2} \sin^{2} \phi$$

$$E_{4d} = A^{2} - 2AB \cos \phi \cos \delta + B^{2} \cos^{2} \phi.$$
 (2)

In Fig. 11  $E_{1d}$  is plotted as a function of azimuth angle,  $\phi$ , for several values of  $\delta$  for B=2A. By taking the difference between the detected signals from opposite pairs of detectors, video signals are obtained that are proportional to  $\sin \phi \cos \delta$  and  $\cos \phi \cos \delta$ , respectively.

Although the operation of the video-direction-finding system is independent of the amplitudes of the two orthogonal modes, it will prove useful in determining bearing errors to find the relationship between them. The amount of available power in the orthogonal TEM and  $TE_{10}$  radial-line modes excited in the biconical antenna by an incident plane wave can be most easily deter-

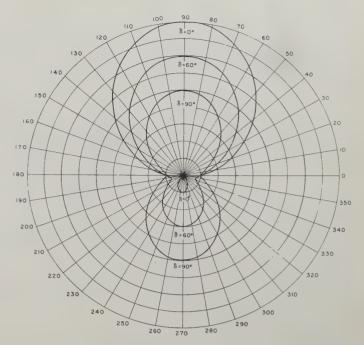


Fig. 11—Received power as a function of azimuth angle for a single detector in the video direction-finder.

mined by considering the directive gain of the biconical antenna when it is supporting each of these modes separately. Consider the case where the biconical antenna extends to infinity and assume that the antenna is transmitting. Then it is seen that at a constant radius the electric-field amplitude of the TEM mode is independent of azimuth angle, while that of the TE<sub>10</sub> mode, which radiates a stationary figure-eight pattern, is proportional to the sine of the azimuth angle. By integrating the electric-field amplitude of each mode separately over all azimuth angles, it is readily shown that the maximum directive gain of the antenna when supporting the TE<sub>10</sub> radial-line mode is twice that when the antenna is supporting the TEM mode. Therefore, when the antenna is used for reception, there is twice as much power available in the TE<sub>10</sub> radial-line mode as there is in the TEM mode. From (1) the power available from the TE<sub>10</sub> radial-line mode is proportional to  $2B^2$ , and the power available from the TEM mode is proportional to  $4A^2$ ; therefore, B=2A. It has been assumed that both modes are perfectly matched into the four waveguides.

The above discussion also assumes that the biconical antenna extends to infinity. In an actual antenna of finite extent but still many wavelengths in circumference, it is clear that relationships similar to those given above will apply, at least within a restricted range of elevation angles above and below horizontal, depending on the vertical directivity of the antenna.

#### APPENDIX II

#### A. Bearing Errors for Video Direction Finder

As mentioned in the text, bearing errors may result from a number of sources, several of which may be analyzed as follows. Unequal Detector Sensitivities

It is shown in Appendix I that, B=2A, hence the video output signals given in (1) become:

It is shown in Appendix I, B=2A, hence the video output signals given in (1) become:

$$E_{1d} = C_1(1 + 4\sin\phi + 4\sin^2\phi)$$

$$E_{2d} = C_2(1 + 4\cos\phi + 4\cos^2\phi)$$

$$E_{3d} = C_3(1 - 4\sin\phi + 4\sin^2\phi)$$

$$E_{4d} = C_4(1 - 4\cos\phi + 4\cos^2\phi),$$
(3)

where  $C_n$  is proportional to the current sensitivity of the nth detector and  $\cos \delta = 1$ .

Taking the difference between opposite channels and applying the resultant signals to the vertical and horizontal plates of an oscilloscope, as before, gives

$$\tan \phi' = \frac{4(C_1 + C_3)\sin\phi + (C_1 - C_3)(1 + 4\sin^2\phi)}{4(C_2 + C_4)\cos\phi + (C_2 - C_4)(1 + 4\cos^2\phi)}, \quad (4)$$

The bearing error is then defined as

$$\Delta \phi = \phi' - \phi. \tag{5}$$

This bearing error has been plotted as a function of true bearing,  $\phi$ , for a number of values of detector output voltages in Fig. 12. A study of the various curves reveals that the minimum bearing errors are obtained (for a given maximum difference between two crystals) when the most sensitive and the least sensitive crystals are placed opposite each other, thus minimizing the difference in sensitivity between adjacent crystals.

#### B. MISMATCHED VIDEO DETECTORS

The effect of mismatched video detectors is most easily determined from the scattering matrix for the ridge-waveguide to the coaxial-line transition section. This transition section is actually a seven-port junction, consisting of four waveguide ports, one TEM mode port in the coaxial line, and two linearly polarized  $TE_{11}$  mode ports oriented at right angles to each other in the coaxial line. If one labels the four waveguide ports Nos. 1, 2, 3, and 4, respectively, the TEM port No. 5, and the two  $TE_{11}$  ports Nos. 6 and 7, the scattering matrix for the perfect lossless junction can be determined as follows:

- 1) If a signal is put in port 5, it will be divided equally among ports 1 to 4 with equal amplitudes and phases, and no signal will emerge from ports 6 and 7. Thus, in the scattering matrix  $S_{55} = S_{65} = S_{75} = 0$  and  $S_{15} = S_{25} = S_{35} = S_{45} = \frac{1}{2}$ .
- 2) Conversely, if four signals of equal amplitudes and phases are put into ports 1 to 4, they will add and emerge from port 5 and none will emerge from ports 6 and 7. Thus,  $S_{n1}+S_{n2}+S_{n3}+S_{n4}=0$ , where n=1, 2, 3, and 4.
- 3) If a signal is put into port 6, and if the plane of polarization of this TE<sub>11</sub> mode is in line with ports 1 and 3, the signal will divide equally between ports 1 and 3, but with opposite phases. Thus,

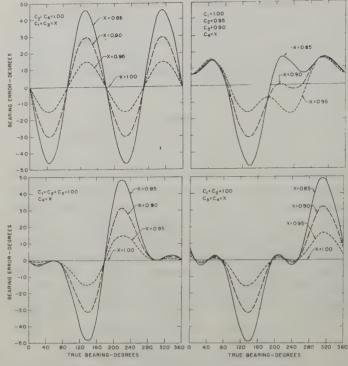


Fig. 12—Bearing error vs true bearing for several values of the sensitivities of the square-law detectors.

$$S_{26} = S_{46} = S_{56} = S_{66} = S_{76} = 0$$
,  $S_{16} = 1/\sqrt{2}$ , and  $S_{36} = -1/\sqrt{2}$ .

- 4) Conversely, if equal amplitude signals with opposite phases are put into ports 1 and 3, the signals will add and all emerge from port 6. Thus,  $S_{n1} S_{n3} = 0$ , where n = 1, 2, 3, and 4.
- 5) Results similar to those obtained in steps 3 and 4 for port 6 can be derived for port 7.
- 6) By symmetry,  $S_{11} = S_{22} = S_{33} = S_{44}$  and  $S_{66} = S_{77}$ .

By combining these results, and noting that the scattering matrix must be symmetrical, the following matrix is obtained:

$$S = \begin{bmatrix} \frac{1}{4} & -\frac{1}{4} & \frac{1}{4} & -\frac{1}{4} & \frac{1}{2} & 1/\sqrt{2} & 0 \\ -\frac{1}{4} & \frac{1}{4} & -\frac{1}{4} & \frac{1}{4} & \frac{1}{2} & 0 & 1/\sqrt{2} \\ \frac{1}{4} & -\frac{1}{4} & \frac{1}{4} & -\frac{1}{4} & \frac{1}{2} & -1/\sqrt{2} & 0 \\ -\frac{1}{4} & \frac{1}{4} & -\frac{1}{4} & \frac{1}{4} & \frac{1}{2} & 0 & -1/\sqrt{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 \\ 1/\sqrt{2} & 0 & -1/\sqrt{2} & 0 & 0 & 0 & 0 \\ 0 & 1/\sqrt{2} & 0 & -1/\sqrt{2} & 0 & 0 & 0 \end{bmatrix}$$
(6)

The use of this matrix makes it very simple to trace any waves which may be reflected back into the system from the detectors.

Let the signals incident on the four detectors be given by (1) for A=2B=1 and  $\cos\delta=1$ . Then, if detector 1 is mismatched, a reflected wave enters port 1 and emerges from the various other ports in such a way that, for small reflections, the resultant field amplitudes are given by

$$E_{1} = (1 - \Gamma^{2})^{1/2}(1 + 2\sin\phi) + \frac{\Gamma}{4}(1 + 2\sin\phi)$$

$$E_{2} = (1 + 2\cos\phi) - \frac{\Gamma}{4}(1 + 2\sin\phi)$$

$$E_{3} = (1 - 2\sin\phi) + \frac{\Gamma}{4}(1 + 2\sin\phi)$$

$$E_{4} = (1 - 2\cos\phi) - \frac{\Gamma}{4}(1 + 2\sin\phi).$$
 (7)

For the sake of simplicity, assume that the reflection coefficient  $\Gamma$  of the mismatched detector is real at the reference planes chosen for the scattering matrix in (6).

The video output voltages for the four square-law detectors with current sensitivities given by  $C_1$ ,  $C_2$ ,  $C_3$ , and  $C_4$ , respectively, are

$$E_{1d} = C_1 \left( \sqrt{1 - \Gamma^2} + \frac{\Gamma}{4} \right)^2 (1 + 2\sin\phi)^2$$

$$E_{2d} = C_2 \left[ (1 + 2\cos\phi)^2 - \frac{\Gamma}{2} (1 + 2\cos\phi)(1 + 2\sin\phi) + \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2 \right]$$

$$E_{2d} = C_3 \left[ (1 - 2\sin\phi)^2 + \frac{\Gamma}{2} (1 - 4\sin^2\phi) + \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2 \right]$$

$$E_{4d} = C_4 \left[ (1 - 2\cos\phi)^2 - \frac{\Gamma}{2} (1 - 2\cos\phi)(1 + 2\sin\phi) + \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2 \right]. \quad (8)$$

then

$$C_1 = \frac{\left(1 - \frac{\Gamma}{12}\right)^2}{\left(\sqrt{1 - \Gamma^2} + \frac{\Gamma}{4}\right)^2} \cdot$$

The four output signals as a function of bearing angle  $\phi$  then become:

$$E_{1d'} = \left(1 - \frac{\Gamma}{12}\right)^2 (1 + 2\sin\phi)^2$$

$$E_{2d'} = (1 + 2\cos\phi)^2 - \frac{\Gamma}{2} (1 + 2\cos\phi)(1 - 2\sin\phi)$$

$$+ \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2$$

$$E_{3d'} = (1 - 2\sin\phi)^2 + \frac{\Gamma}{2} (1 - 4\sin^2\phi)$$

$$+ \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2$$

$$E_{4d'} = (1 - 2\cos\phi)^2 - \frac{\Gamma}{2} (1 - 2\cos\phi)(1 + 2\sin\phi)$$

$$+ \frac{\Gamma^2}{16} (1 + 2\sin\phi)^2.$$

Taking the ratio of the difference between opposite channels, as before, gives for the indicated bearing angle  $\phi'$ :

$$\tan \phi' = \frac{E_v}{E_h} = \frac{\sin \phi - \frac{\Gamma}{12} (1 + 2 \sin \phi)(1 - \sin \phi) - \frac{\Gamma^2}{144} (1 + 2 \sin \phi)^2}{\cos \phi \left[1 - \frac{\Gamma}{4} (1 + 2 \sin \phi)\right]}.$$

In practice, the sensitivities of the four detectors will be equalized by rotating the antenna until the output from each detector is maximized when the antenna is receiving a signal from a distant source of constant amplitude. A radio frequency or a video attenuator can then be adjusted so that the maximum signal from each detector is the same. Thus, in (8),  $E_{1d}$  will have a maximum at  $\phi = \pi/2$  of 9  $C_1(\sqrt{1-1^2} + \Gamma/4)^2$ . Similarly,  $E_{2d}$  will have a maximum at  $\phi = 0$  of  $C_2(3-\Gamma/4)^2$ .

The maxima for the output voltages  $E_{3d}$  and  $E_{4d}$  are the same as those for  $E_{2d}$ , with  $C_3$  replacing  $C_2$  in  $E_{3d}$  and  $C_4$  replacing  $C_2$  in  $E_{4d}$ . If these four signals are equalized, and if the following constants are arbitrarily set equal to unity

$$C_2 = C_3 = C_4 = 1$$
,

The bearing error, defined as

$$\Delta \phi = \phi' - \phi$$

is plotted in Fig. 13 as a function of the true bearing for several values of the reflection coefficient. The reflection coefficient is related to the input vswr of the detector in the usual way:

$$vswr = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

which for the values shown in Fig. 13 are

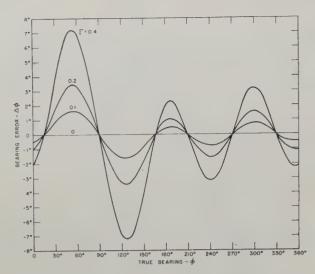


Fig. 13—Bearing errors as a function of true bearing for one mismatched detector with the reflection coefficient shown.

It can be seen that if the detector is matched to a vswr less than about 1.3, the maximum bearing errors will be less than  $2^{\circ}$ . It can be readily shown from the scattering matrix that if all of the detectors are mismatched such that  $\Gamma_1 = \Gamma_2 = \Gamma_3 = \Gamma_4$ , then the bearing errors are zero everywhere. This is another case where symmetry is an aid, making it desirable to use four detectors and detector mounts that are identical to each other in as many respects as possible, in order to minimize the bearing errors resulting from any residual reflections.

# C. Inadequate Attenuation of Higher-Order Modes

Since the experimental evidence indicates that the  $TE_{21}$  coaxial-line mode is the principal higher-order mode contributing to bearing errors, it will be treated here. If the  $TE_{21}$  mode is matched into the four waveguides, it excites a signal in them whose amplitude is the same as that excited by the  $TE_{11}$  mode, since the directive gains of the  $TE_{10}$  and the  $TE_{20}$  radial-line modes are equal. If  $\alpha$  represents the cutoff attenuation of the  $TE_{21}$  mode in the coaxial line, as well as any mismatch loss, the resultant field amplitudes in the four waveguides become:

$$E_1 = 1 + 2 \sin \phi - 2\alpha \cos 2\phi$$
  
 $E_2 = 1 + 2 \cos \phi + 2\alpha \cos 2\phi$   
 $E_3 = 1 - 2 \sin \phi - 2\alpha \cos 2\phi$ 

$$E_3 = 1 - 2 \sin \phi - 2\alpha \cos 2\phi$$
$$E_4 = 1 - 2 \cos \phi + 2\alpha \cos 2\phi$$

where  $\delta$  has again been assumed equal to zero.

If these fields are incident on identical, matched, square-law detectors, the ratio of the differences between opposite detectors gives for the indicated bearing angle,  $\phi'$ ,

$$\tan \phi' = \frac{E_v}{E_h} = \frac{1 - 2\alpha \cos 2\phi}{1 + 2\alpha \cos 2\phi} \tan \phi.$$

The bearing errors, given by  $\phi' - \phi$ , have a period of  $\pi/2$  in  $\phi$  and have the following typical amplitudes:

α	Attenuation	Bearing Error
0.05	26 db	±2.7°
0.025	32 db	±1.4°

# APPENDIX III

# A. Construction and Performance Data for the Components

#### Biconical Antenna

The biconical antenna, illustrated at the top of Fig. 6, was formed by drawing two round flat sheets over a suitably shaped die. The flared coaxial line feeding the antenna was machined. The antenna has a diameter of 17.5 inches and a vertical aperture of 4 inches. The vswr looking from the coaxial line into the antenna was less than 1.18 over the 8.2 to 12.4 kmc band for the TEM mode.

### Ridge-Waveguide to Coaxial-Line Transition Section

This transition section, shown just beneath the antenna in Fig. 6, has a total length of 3 inches. The round inner conductor, machined from aluminum, tapers linearly from a diameter of 0.4 inch at the top to 0.7 inch at the bottom. The outer conductor, of electroformed copper, tapers from a round inside diameter of 0.75 inch at the top to a square with an inside dimension of 0.9 inch on a side. At the same time, four ridges taper along the centers of the flat sides from zero height at the top to a maximum height of 0.040 inch at the bottom. The division into four-ridge-waveguide channels is accomplished at the bottom with four thin fins whose knife edges are perpendicular to the axis and extend from the inner conductor to the corners of the square outer conductor. The vswr of the transition section is less than 1.3 for the TEM mode and less than 1.22 for the TE11 mode over the 8.2 to 12.4 kmc band.

# Rectangular-Waveguide to Ridge-Waveguide Taper Section

The taper section, shown next in Fig. 6, has a total length of 5 inches and was electroformed on aluminum mandrels. The vswr for each of the four identical channels is less than 1.12 over the 8.2 to 12.4 kmc band.

# Waveguide 45-Degree-Twist Section

This multiple-channel twist section was formed from stacks of thin shims strung together on wires and soldered. The electrical lengths of the four channels were adjusted to within  $\pm 0.7^{\circ}$  of each other over the 8.2 to 12.4 kmc band. This section and the technique used to construct it are described by Jones and Honey.

<sup>&</sup>lt;sup>4</sup> E. M. T. Jones and R. C. Honey, "A novel technique for making precision waveguide twists," IRE TRANS., vol. MTT-4, pp. 131-132; April, 1956.

Ouadrature Hybrid Junctions or 3-DB Directional Coup-

Two Hewlett-Packard X-752A multihole directional couplers were selected whose couplings differed from each other by less than 0.1 db and varied from -2.7 db to -3.3 db over the 8.2 to 12.4 kmc band.

# Waveguide Bends

These bends, shown at the bottom of Fig. 6, were all electroformed on precision-machined aluminum mandrels, which were subsequently dissolved out in boiling sodium hydroxide. The electrical lengths of the various paths were checked and adjusted, where necessary, until they were within a degree of each other over the 8.2 to 12.4 kmc band.

#### Broad-Band Magic-T's

A pair of Airtron's No. 44055 broad-band Magic-T's were obtained for this purpose, and were oriented in the manner illustrated in Fig. 6. They were tested and found to have minimum isolations of 35 db over the 8.2 to 12.4 kmc band and a maximum vswr of 1.7.

#### T Junction

This T junction, whose symmetrical arm forms the TEM input terminal for the multiplexing antenna, is simply a carefully constructed tapered waveguide bifurcation. It splits the power incident from the symmetrical arm into two equal components within at least +0.1 db. The symmetrical arm is matched to a vswr less than 1.02 over most of the 8.2 to 12.4 kmc band, increasing to 1.05 at the low end of the band. The total length of the junction is  $3\frac{1}{2}$  inches.

#### Acknowledgment

The authors wish to thank Seymour B. Cohn for his advice and assistance.

# Radio Propagation Above 40 MC Over Irregular Terrain\*

JOHN J. EGLI†

Summary-Radio transmissions in the vhf and uhf frequency region over land areas always contend with the irregularities of the terrain and the presence thereon of dispersed quantities of trees, buildings, and other man-made structures, or wave propagation incumbrances. The determination of path attenuation is not easily satisfied by simple, curved, or plane earth calculations. However, quantitative wave propagation data are available in varying degrees which take into account conditions experienced by fixed-to-fixed and fixed-to-moving transmissions over irregular terrain. This available statistical wave propagation information on terrain effects vs frequency, antenna height, polarization, and distance is analyzed, expressed by empirical formulas, and presented in the form of nomographs and correction curves amenable for use by the systems engineer.

#### INTRODUCTION

ADIO transmissions above 40 mc more often than not take place over irregular terrain so that the ordinary method of calculating propagation attenuation over plane earth, curved earth, and simple diffraction edges becomes unsatisfactory. As one moves about in irregular terrain in a vehicle, the received signal is characterized by a slow variation dependent on the major features of the terrain and on distance, and by a

\* Original manuscript received by the IRE, February 5, 1957; revised manuscript received, June 7, 1957. † U.S. Army Signal Eng. Labs., Fort Monmouth, N. J.

fast variation about the median in a small sector which is independent of the transmission distance but is dependent on the speed of the vehicle and on the frequency of the transmission.

In the practical sense, the systems engineer is interested in knowing how well his equipment will be able to service an area, or how well his equipment will cover many areas in a very large area. Some of these areas may typify curved earth while other areas may be highly mountainous; all others will be in between these areas in terms of surface irregularity.

This irregular terrain has dotted on it, trees, buildings, and other man-made wave propagation encumbrances. If one could run the entire gamut of terrain conditions in a statistical manner and arrive at the transmission loss which would have to be designed into a system at a given frequency to provide the desired coverage, it would appear that such information would be invaluable to the systems engineer.

Fortunately, such data have been collected and studied by the Federal Communications Commission for use in connection with their studies of the vhf and uhf television allocation problems, and by others in connection with mobile service.

The majority of the terrain data,1 on which the following material will be derived, are based on survey data taken by commercial organizations in various parts of the country including New York, N. Y.; Washington, D. C.; Cleveland, and Toledo, Ohio; Harrisburg, Easton, Reading, Pittsburgh, and Scranton, Pa.; Kansas City, Mo.; Cedar Rapids, Iowa; San Francisco, Calif.; Bridgeport, Conn.; Nashville, Tenn.; Fort Wayne, Ind.; Richmond and Norfolk, Va.; and Newark, N. I. In each of these locations, a number of radials were investigated. In all, over the uhf range, 288 to 910 mc, 804 miles on 63 radials are represented in the data. The method of measurement, while not the same at all locations, falls into three categories: continuous mobile recording sampling every 0.2 mile, spot measurements properly weighted so as to be considered unbiased, and clusters of measurements. In the vhf region, 50 to 250 mc, approximately 1400 measurements, consisting of continuous data analyzed over 1-mile and 2-mile sectors, are included in the data.

In discussing service area, we will be concerned with expressing the percentage of locations one could expect to cover statistically at a predescribed distance. Thus, if one arbitrarily divides a 10-mile circle into 100 equal parts with each division represented by a point (location) and superimposes this configuration on the statistically derived landscape represented by the data, then 10 per cent coverage would mean that 10 of the points (locations) would receive satisfactory or better transmissions, while at the balance of the points reception would not be possible. Likewise, when considering 90 per cent coverage, 90 of the 100 points would receive transmissions while the balance would have no reception.

Actually, in dividing the circle into 100 locations, it was assumed that these locations represented the median value of signals in the immediate vicinity of the location, since one finds that in the immediate vicinity of a given location, say a few hundred feet, there will be fine variations in received field strength.

TERRAIN-FREQUENCY, DISTANCE DEPENDENCE

The theoretical plane earth field strength expression is given by

$$E = \frac{h_t h_r f}{95d^2} \sqrt{P_t}$$

where

E =field intensity in microvolts per meter  $h_t =$ transmitting antenna height in feet  $h_r =$ receiving antenna height in feet

f=transmission frequency in megacycles d=distance from transmitter in miles  $P_t$ =effective radiated power in watts.

Eq. (1) is limited to those geographical areas which are similar to plane earth, such as relatively short overwater and very flat barren land paths. Even in these areas man has erected bridges, Texas towers, billboards, and so forth, which alter considerably the propagation characteristics as expressed by the theoretical plane earth formula.

While the theoretical received field strength increases with frequency, all other constraints being the same, it is important to note that the voltage across the input to a receiver will be the same at all frequencies when the receiving antenna is a half-wave dipole. However, if the antenna at the higher frequency is constructed so that it presents an effective area equal to that of the half-wave dipole at the lower frequency, then this increased field strength at the higher frequency will be realized as increased voltage at the input to the receiver.

The measured field strength data1 over irregular terrain were compared with what one could expect over plane earth rather than curved earth, since the best median field strength data fit for distances up to 30 to 40 miles shows that the inverse distance squared trend for plane earth is better than the curved earth field, at least for low antenna heights. Beyond 30 miles to 40 miles the data are sufficiently meager as to be unworthy of analysis as a representive quantity of data. Therefore, the median field at a given frequency can be described by the theoretical plane earth field intensity, less the median deviation therefrom. This median deviation data from the theoretical plane earth field, called terrain factor, is shown in Fig. 1. The straight line on this figure very nearly passes through all the FCC data, and it will be noted that the deviation from the plane earth field strength varies inversely with the frequency and is independent of distance. The intersection of this line with the theoretical plane earth field strength is at 40 mc, so that the variation with frequency is with respect to this frequency.

With this statistical information, (1) becomes empirically for the median field at the 50 percentile locations,  $E_{50}$ , independent of frequency

$$E_{50} = \frac{40h_t h_r}{95d^2} \sqrt{P_t}.$$
 (2)

This  $E_{50}$  field strength may be obtained quickly from the nomograph, Fig. 2.

The theoretical plane earth received power between half-wave dipoles (3) is independent of frequency.

$$P_r = 0.345 \left(\frac{h_t h_r}{d^2}\right)^2 P_t \times 10^{-14}.$$
 (3)

Making use of the power law variation with frequency for the median deviation from the theoretical plane

<sup>&</sup>lt;sup>1</sup> H. Fine, "UHF Propagation Within Line of Sight," FCC, TRR Rep. No. 2.4.12; June 1, 1951. Contains material taken from K. A. Norton, M. Schulkin, and R. S. Kirby, "Ground Wave Propagation Over Irregular Terrain at Frequencies Above 50 MC," Ref. C, Rep. of the Ad Hoc Committee of the FCC for the Evaluation of the Radio Propagation Factors Concerning the Television and Frequency Modulation Broadcasting Services in the Frequency Range Between 50 and 250 MC; June 6, 1949.

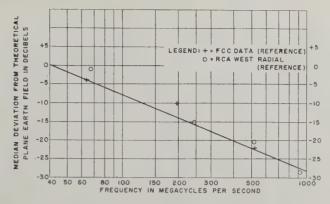


Fig. 1—Median terrain factor for fixed-to-vehicular or mobile service.

earth field, Fig. 1, (3) becomes empirically,

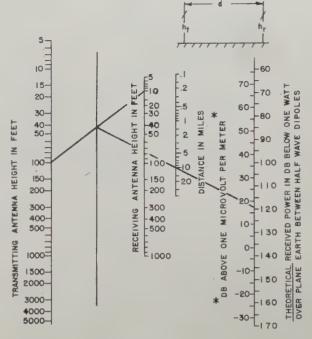
$$P_{50} = 0.345 \left(\frac{h_t h_r}{d^2}\right)^2 \left(\frac{40}{f}\right)^2 P_t \times 10^{-14}. \tag{4}$$

Eqs. (2) and (4) show that nature, by interposing terrain features, has essentially placed in juxtaposition the frequency dependence of the field strength and received power above 40 mc over plane earth. Thus, while the theoretical received field strength over plane earth increases with frequency, the median received field intensity above 40 mc over irregular terrain is independent of frequency, and while the theoretical received power between half-wave dipole antennas is independent of frequency, over irregular terrain the median received power above 40 mc varies inversely as the frequency squared.

For the purpose of the systems engineer, in making irregular terrain calculations it is preferable to use the plane earth received power (3) shown in nomographic form in Fig. 2, in its theoretical form because field strength, median value statistically derived, and received power theoretically derived are, at this point of exploration of irregular terrain propagation, independent of frequency.

It is interesting to note that if one determines from diffraction theory the depth of hills2 which will result in the median loss of Fig. 1, the statistical irregular terrain can be conceived as hills with a depth of about 500 feet. It is also interesting to note that the New York west radial terrain over which data are available<sup>3</sup> has an irregular depression of about 500 feet, 12 miles in extent and distance from the transmitter. Most of the data were accumulated in this portion of the radial, and the median values below plane earth theory are shown in Fig. 1 as the composite for the entire radial.

At this point in the paper it will be well to assume a rather simple problem and use it as a means of exemplifying the development of the material to be presented.



\*50 PERCENTILE LOCATION MEDIAN FIELD STRENGTH

Fig. 2—Received power over plane earth and 50 per cent location median field strength—one watt radiated.

#### Assume:

Transmission frequency, 150 mc Dipole antennas, half-wave Transmitting antenna height, 100 feet Receiving antenna height, 10 feet Service range, 10 miles Service to 90 per cent of locations at 10 miles 50 kc IF bandwidth Suburban noise No transmission line losses.

Required: Transmitter power output.

The theoretical received power in db below one watt will be from Fig. 2, 119 dbw. The field strength at 50 per cent of the locations, Fig. 2, will be 17.5 db above one microvolt per meter, one watt radiated.

### TERRAIN-FREQUENCY DEPENDENCE

If one explores the data<sup>1</sup> in terms of the distribution of received field strength over irregular terrain, one finds that the over-all terrain distribution when plotted in decibels above the theoretical plane earth attenuation. is log-normally distributed. Thus, on probability paper, the terrain distribution will appear linear and may be described by its median value and standard deviation, Fig. 3. The terrain distribution of field intensity in the vhf band, taken at a center frequency of 127.5 mc appears to have an over-all standard deviation of 8.3 db, while the terrain distribution of field intensity in the uhf region centered around 510 mc, appears to have an over-all standard deviation of 11.6 db. Of course, the median deviation from theoretical plane earth field is

<sup>&</sup>lt;sup>2</sup> K. Bullington, "Radio propagation variations at vhf and uhf,"

Proc. IRE, vol. 38, pp. 27-32; January, 1950.

<sup>2</sup> G. G. Brown, J. Epstein, and D. W. Peterson, "Comparative propagation measurements; television transmitters at 67.25, 288, 510 and 910 megacycles," RCA Rev., vol. 9, pp. 171-201; June, 1948.

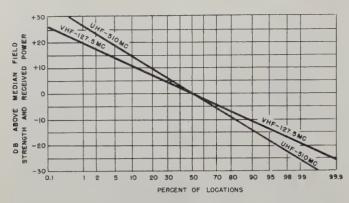


Fig. 3-VHF and uhf terrain distribution.

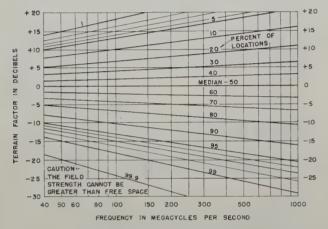


Fig. 4—Fixed-to-vehicular or mobile service field strength terrain factor.

displaced 12 db by the terrain factor for the two frequencies, Fig. 1. From this standard deviation data, Fig. 4 has been prepared which permits the determination of the correction factor to the  $E_{50}$  field strength when the received field strength to other than the 50 percentile location is desired. For example, as previously determined,  $E_{50}$  was 17.5 db above one microvolt per meter. Applying the terrain correction factor of -11.5 db for the 90 percentile location results in a median received field strength at the 90 percentile location of 6 db above one microvolt per meter, one watt radiated. This value of field strength does not exceed the free space value for 10 miles of 53 db above one microvolt per meter obtained from Fig. 5. Under conditions of greatly increased antenna heights and/or service to a small percentile of locations, the calculated field strength could exceed the free space field. If such is the case, the free space field should be used. It is interesting to note that while the median field strength (2) and terrain factor for 50 per cent of the locations (Fig. 4), are independent of frequency, for percentages of locations less than 50, the field strength increases with frequency, and for  $E_{2.3}$  the field strength varies as  $f^{1/2}$ . Likewise for percentages of locations greater than 50, the field strength decreases with frequency and for  $E_{97.7}$  varies inversely as  $f^{1/2}$ .

Likewise, Fig. 6 has been prepared to reflect the cor-

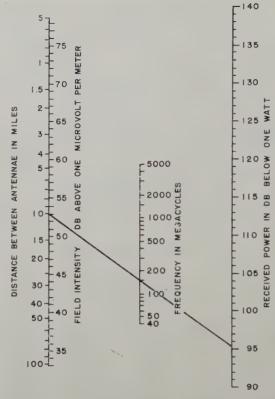


Fig. 5—Free space—one watt radiated between half-wave dipoles

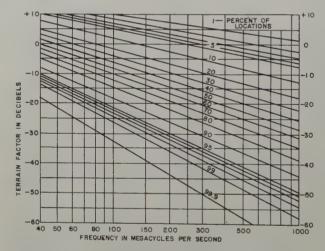


Fig. 6—Received power terrain factor for fixed-tovehicular or mobile service.

rection factor to the theoretical plane earth received power imposed by irregular terrain. The  $P_{50}$  value follows an inverse frequency squared relation as per (4), at  $P_{97.7}$  an inverse frequency cubed relation, and at  $P_{2.3}$  an inverse frequency relation. As previously determined, the theoretical received power is -119 dbw. The terrain correction factor for the 90 percentile location at 150 mc is -23 db, and the received power at this location will be -142 dbw, or the half-wave dipole-to-half-wave-dipole path attenuation for this degree of service is 142 db. The free space received power is -95.4 dbw from Fig. 3 which exceeds that for the 90 percentile location.

### TERRAIN-TRANSMITTING ANTENNA HEIGHT DEPENDENCE

The transmitting antenna height, used in conjunction with the data is defined as the height above the median. 2-10 mile terrain level. This rule has not proven as reliable as one might expect, since it does not take into account the terrain within 2 miles or beyond 10 miles. For purposes of this report the effective height of the antenna will be the height of the antenna above plane earth. In actual practice the transmitting antenna heights could be taken as the effective height above local terrain. For all practical purposes, the data confirmed that the received field strength increased linearly with transmitting antenna height. Transmitter height-gain tests made around the New York area4 seem to indicate that in poor service locations the effect of transmitting antenna height increase is somewhat less than one would theoretically predict. In median or 50 percentile locations the height gain would approximate the theoretical expected height gain, and for good service locations the height gain would be somewhat more than the theoretical. For purposes of this paper, the formulas and nomographs reflect a linear high gain for transmitting antenna height.

# TERRAIN-RECEIVING ANTENNA HEIGHT DEPENDENCE

Receiving antenna height is the effective height above local terrain. The data do not appear to support any clear-cut variation of field strength with change in receiving antenna height. For receiving antennas which clear surrounding terrain features, the height gain appears to be linear. For receiving antennas which do not clear the surrounding terrain features, no orderly pattern is discernible. However, test results analyzed statistically, show that in the 6 to 30 feet category, the field strength appears to support a square-root height gain variation. Above 30 feet, the height gain is linear. This variation is reflected in the nomograph of Fig. 2.

In practice, when using low antenna heights, as pointed out in the New York tests,4 the dependence of field strength upon receiving antenna height is quite variable. When locating in a given area, within the confines of available antenna height, the maximum field strength should be found.

# TERRAIN FADING

Both the vhf and uhf studies indicate that the time fading is much smaller for the distances involved than the terrain variation, and may be neglected as a power balance factor in equipment design. In the fear of being misunderstood, suppose equipment is designed for vehicular operation to cover 90 per cent of the locations, at

<sup>4</sup> J. Epstein and D. W. Peterson, "An experimental study of wave propagation at 850 mc," Proc. IRE, vol. 41, pp. 595-611; May, 1953.

10 miles from the transmitter. Based on statistical terrain data, the variation in median signal throughout the terrain is far in excess of what the long-time fading would be between two fixed locations. However, fading becomes important for fixed service work. A subscriber land-based for an extended period of time in a poor location, marginal signal, might well compensate for the long-time fading which will ensue by moving to the optimum spot in the small area in which he is to be located, and also by having means for elevating his antenna, which can now be changed to a directional antenna, to the optimum height within the height-raising capability of his antenna system. These two expedients should compensate for time fading and be reflected in a highly reliable transmission circuit.

#### TERRAIN-ANTENNA POLARIZATION

Theoretically, over plane earth at antenna heights greater than a wavelength and for small angles between the direct and reflected rays, as is the case for irregular terrain transmissions, polarization has negligible effect on the behavior of radio waves above 40 mc. Experimental evidence<sup>5,6</sup> over irregular terrain of the received characteristics of polarized waves appears in general to verify the above. While it appears that vertical polarization is somewhat better directly behind hills or deep in the shadow area, horizontally polarized waves afford better reception in back of, but away from, the deep shadows of hills. In wooded areas, the attenuation is less for horizontally polarized transmissions than for vertically polarized transmissions below 300 to 500 mc. In total, little difference can be detected in the average propagation characteristics.

There is one exception to the latter statement and it concerns propagation using antenna heights less than one wavelength. In this case the ground wave is dominant and theoretically vertical polarization provides an apparent height gain over horizontal polarization. This effect is shown in Fig. 7 and pertains only to vertical polarization since for horizontal polarization the effective height is essentially the actual height at frequencies above 40 mc. As shown in Fig. 7, the effective height also depends on the conductivity of the soil over which the transmission will be effective. Unfortunately, as far as the author knows, terrain-statistical data are lacking on the propagation effects resulting from the use of very low vertically polarized antenna heights in the lower vhf region. Until such time as this theoretical information can be placed in dispute statistically by tests, it is

<sup>&</sup>lt;sup>5</sup> J. S. McPetrie and J. A. Saxton, "An experimental investigation of the propagation of radiation having wavelengths of 2 and 3 meters," J. IEE, vol. 87, pp. 146–153; August, 1940.

<sup>6</sup> J. A. Saxton and B. N. Harden, "Ground-wave field-strength surveys at 100 and 600 mc/s," Proc. IEE, vol. 101, part 3, pp. 215–221, July 1054.

<sup>221;</sup> July, 1954.

<sup>7</sup> K. Bullington, "Radio propagation at frequencies above 30 megacycles," Proc. IRE, vol. 35, pp. 1122–1136; October, 1947.

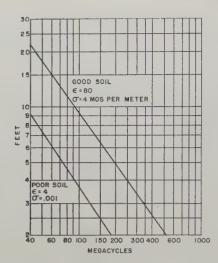


Fig. 7—Minimum effective antenna height for vertical polarization.

proposed that when vertically polarized transmissions are under consideration, Fig. 7 be used in finalizing the effective height of low antennas.

In our problem at 150 mc with an antenna height of 10 feet it can be seen from Fig. 7 that even with vertical polarization this height is also the effective height. If the problem had been one of transmission at 40 mc, then in using Fig. 2 the height would have remained the same for poor soil conditions, but would have to be taken as 23 feet over good soil conditions.

#### TERRAIN-SMALL SECTOR FIELD STRENGTH VARIATION

As noted earlier, there is a fine amplitude variation about the median in a small distance or area which is independent of the distance from the radiation source. Some studies indicate that these fine variations of field strength have a normal distribution which appears to be independent of frequency with a standard deviation of 5.5 db. Other studies,8 indicate a Rayleigh distribution, Fig. 8. The latter appears more likely because the studies which indicate a normal distribution were taken over distances which perhaps exceeded the small sector variation. However the Rayleigh type fading may only occur and be applicable in areas replete with buildings. etc. In open areas the distribution may be log-normal over a small sector. Between the 10 and 90 per cent values of these distributions there is very little difference in the two distributions. The amplitude distribution is the same at all frequencies indicating that the range of constructive and destructive phase interference or standing wave effects is complete. However, the number of constructive and destructive interferences increases in a given distance or area with frequency.

Tests<sup>9</sup> conducted in the Phoenix, Ariz. area indicate that the average vehicle travel between these fine signal

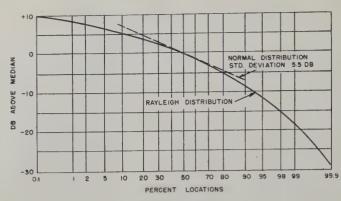


Fig. 8—Terrain-small sector variation.

minima is one wavelength in free space, while in the direction away from or toward the radiation, the distance between signal minima is the free space half-wave distance. With this information, in vehicular service the small sector amplitude fluctuations in received carrier level will increase in rapidity with frequency and the speed of the vehicle, or

$$A = \frac{v}{\lambda/2}$$
, and in practical terms,  $A = 0.003 \, fv$  (5)

where A is the average amplitude fluctuation rate in cps, f is the radio carrier frequency in mc, and v is the velocity of the vehicle in the direction of transmission in miles per hour. For ready use, (5) has been prepared in the form of a nomograph, Fig. 9. It shows, for example, that at 150 mc the received field in a vehicle traveling at 40 miles per hour in the direction of transmission would have an average fluctuation rate of 18 cps. For vehicular service, this is the rate which would have to be considered in the design of age circuitry with the audio or intelligence pass band designed above this frequency.

The small sector variations at 90 mc<sup>10</sup> appear to be small in open flat country and much greater in built-up areas as might be expected. The variations in built-up and treed areas appear greater for vertically polarized transmissions than for horizontally polarized transmissions.

Another characteristic of these variations which one would expect is that the higher the frequency, the steeper the fall and rise in field strength. In general, the variations appear to be deeper with the time between rise and fall smaller. Maximum envelopes occurring during a test<sup>9</sup> are shown in Fig. 10. At 15 db down, the "outage time" on 459 mc may be in the order of a few milliseconds at vehicle speeds of 40 miles per hour with perhaps no noticeable effect on speech transmissions, whereas at 156 mc the outage time at this level could cause the loss of voice information.

Unfortunately, data were not found which would permit an expression either quantitatively or qualitatively as to the useful distribution or design point criteria of

<sup>&</sup>lt;sup>8</sup> W. R. Youug, Jr., "Mobile radio transmission compared at 150 to 3700 mc," Bell Sys. Tech. J., vol. 31, pp. 1068-1085; November, 1952.

<sup>&</sup>lt;sup>9</sup> C. F. Meyer and D. Soule, "Field Strength Study," Motorola, Inc.; February, 1956. Work performed under Signal Corps Contract DA-36-039-sc-64737.

<sup>&</sup>lt;sup>10</sup> H. L. Kirke, R. A. Rowden, and G. I. Ross, "A vhf field-strength survey on 90 mc/s," *Proc. IEE*, vol. 98, part 3, pp. 343–359; September, 1951.

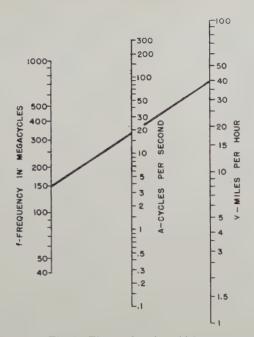


Fig. 9-Fluctuations in vehicles.

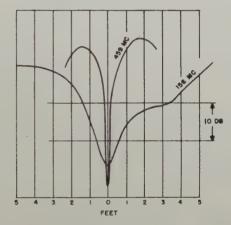


Fig. 10—Maximum small sector variation.

these small sector field strength variations. It may well be, at least for the present, that equipment should be designed to the median value of these find grain variations for the percentage of locations service desired.

#### TERRAIN-WIDE MODULATION BANDWIDTH EFFECTS

The field strength variations discussed so far have been those taken over a very narrow bandwidth of the transmission frequency. On wide-band systems distortion effects may be introduced resulting from propagation via more than one path. These distortions may cause cross talk in multichannel voice systems, or shadows in television reception. This subject will be touched on lightly because not very much statistical data are available nor is literature available on the effects of multipath propagation on various types of modulation. The severity of multipath distortion<sup>11</sup> ap-

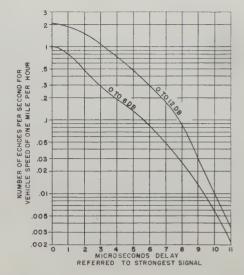


Fig. 11—Echoes in vehicles from a fixed transmission.

pears qualitatively to be independent of frequency and wave polarization, at least within the frequency range of 60 to 3300 mc. The consequences of multipath propagation are not serious for fixed transmission conditions, yet may be very serious in moving situations. For fixed service, movements of the receiving antenna either horizontally or vertically for a distance in the order of a few wavelengths ordinarily cleans up multipath distorted patterns in television reception. More multipath distortion appears in highly built-up and mountainous areas where large off-path reflecting surfaces are present. Directive antennas greatly reduce multipath effects, 11 which means that for equal antenna apertures, the use of the higher frequencies will result in less multipath distortion.

The only good statistical results, unfortunately unrelated to all of the terrain data made use of herein and therefore not representative of all the conditions on which this paper is based, are based on tests in the New York area, 12 where one encounters considerable, and perhaps the worst, multipath propagation conditions. In order to understand the difficulties one may encounter in engineering vehicular wide band systems, the New York data,12 have been altered (Fig. 11) to reflect the number of echoes per second for a vehicle speed of one mile per hour vs delay of these echoes with amplitudes between 0 and 6 db less than the strongest received signal. Thus a remote television transmitter installed in a vehicle patroling New York at 30 miles per hour would present to the fixed television receiver a picture with thirty, 0- to 6-db echoes per second having \(\frac{1}{4}\)-\(\mu\)sec delay, 9 shadows per second having 3-usec delay, and so forth. Besides this ghosting of the picture that is taking place, the synchronous circuit of the television receiver is in essence flip-flopping from the direct signal path amplitude to

<sup>&</sup>lt;sup>11</sup> D. W. Peterson, "Army Television Problems Phase II Tasks 1 and 2 Final Report," January, 1956, RCA. Work performed under a Signal Corps Contract No. DA-36-039-sc-64438.

<sup>&</sup>lt;sup>12</sup> W. R. Young, Jr. and L. Y. Lacy, "Echoes in transmission at 450 megacycles from land-to-car radio units," Proc. IRE, vol. 38, pp. 255-258; March, 1950.

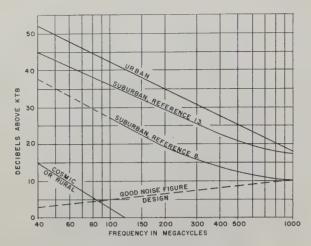


Fig. 12—Median indigenous noise.

the multipath signal amplitude when the ghost signal is the stronger of the two.

#### Indigenous Noise

While the relationship between received signal and frequency over irregular terrain has been covered pretty well, another important power balance factor in systems design is the establishment of the noise level of the receiver, or the signal required to assure satisfactory communication. Noise in the frequency range above 40 mc is mainly caused by man-made noise. The general classifications are rural, suburban or small town, and urban noise. Cosmic noise is still present up to 100 mc. Collectively this noise can be termed indigenous noise.

The extent to which this indigenous noise acts upon a receiver is shown in Fig. 12. Two curves have been drawn for suburban noise since the material for these curves have been drawn from two separate references. 8,18 The lower suburban noise curve is representative of the median indigenous noise experienced in areas suburban to New York, with extrapolated data shown by the dotted portion of the curve. The urban noise data taken from these same two references dovetailed into the same curve. The dotted curve represents the noise figure of a currently well-designed receiver and is shown only to give the figure perspective. The indigenous noise can be referenced with respect to the thermal noise, ktb, of a receiver and is shown in Fig. 12 as the correction factor which must be applied to ktb level, Fig. 13(b).

The difficulty in the use of these curves lies in just what level of noise should be applied in systems design work. Unfortunately indigenous noise data were not collected along with the field strength data. If this had been done a distribution of the magnitude of noise over the areas in which the field strength data were taken would have been available. It would appear that equipment designed for general use should at least consider the lower suburban curve of Fig. 11 with the thought

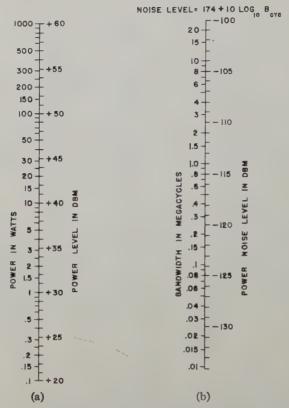


Fig. 13—(a) Conversion of power to dbm. (b) Conversion of bandwidth to thermal noise level.

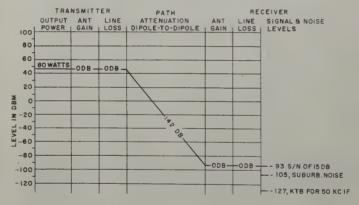


Fig. 14—Power level diagram.

that in urban areas advantage might be taken of the height-gain in these areas.

#### PROBLEM SOLUTION

The entire problem is reviewed in Fig. 14 in the form of a power level diagram. Working the level diagram from the ktb level of -127 dbm obtained from Fig. 13(b), for a 50 kc IF, suburban noise and not noise figure plus approximately 12 db, establishes the lowest rf signal, -93 dbm, for an acceptable signal-to-noise ratio. Assuming no transmission line losses to the two dipole antennas and with the path attenuation loss over 10 miles of irregular terrain to the 90 percentile location of 142 db, one arrives at a required transmitter power of 49 dbm or 80 watts, Fig. 13(a).

<sup>&</sup>lt;sup>13</sup> Federal Telephone and Radio Corp., "Reference Data for Radio Engineers," 3rd ed., p. 442; 1949.

### VEHICULAR-TO-VEHICULAR TRANSMISSIONS

The entire discussion thus far has dealt with the subject of fixed-to-vehicular, or fixed-to-mobile transmissions over irregular terrain. It is in these subjects that data exist, while in the feld of vehicular-to-vehicular transmission good statistical data are nonexistent, at least to the knowledge of the writer.

If one makes the reasonable assumption that the terrain factor will not change whether we deal with the moving-to-moving, fixed-to-fixed, or fixed-to-moving situations, then the median signal received by a vehicle in motion from another vehicle in motion is precisely that given in Fig. 4. However, by statistical theory, <sup>14</sup> it would appear that the standard deviation would be the square root of the sum of the variances of two fixed-tomoving distributions which in this type of transmission can be considered of the same magnitude. Thus the standard deviation for vehicular-to-vehicular transmission is the  $\sqrt{2}$  times the standard deviation for the fixed-to-vehicular transmission. This is in essence the correction factor which must be applied to Fig. 6, in order to obtain the vehicular-to-vehicular received power terrain factor shown in Fig. 15. If the given problem were a vehicular-to-vehicular system, fictitiously assuming antenna heights were maintained for this service, the path attenuation at 10 miles to the 90 percentile location would be 119 db, from Fig. 2, plus 32.5 db, from Fig. 15, or 151.5 db compared to a path attenuation of 142 db derived earlier in this paper for the fixed-to-vehicular or mobile transmission. The transmitter power level of 49 dbm, on Fig. 14, must be raised to 58.5 dbm or 700 watts for vehicular-to-vehicular equivalent service.

#### REMARKS

The statistical method of handling propagation over irregular terrain can be used in frequency assignment studies to determine the number of rf channels which should be designed into equipment for cochannel and adjacent channel feld service. It has important usage in vulnerability studies of mutual interference, intentional and unintentional jamming, and countermeasures. It also appears to have application in spectrum allocation studies.

Of course the burning question of how well a particular piece of equipment will act in a given environment

<sup>14</sup> A. Hald, "Statistical Theory with Engineering Applications," John Wiley and Sons, New York, N. Y.; 1952.

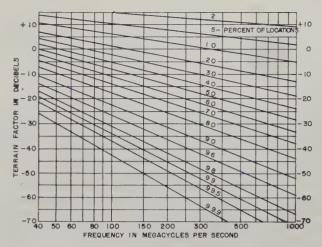


Fig. 15—Vehicular-to-vehicular received power terrain factor.

is difficult to answer. If the terrain is less irregular than the statistical irregular terrain, then better than predicted performance should result. On the other hand, in terrain more irregular than the statistical, a poorer performance should result. However, field operational procedures should be developed which permit a rapid evaluation of the service coverage from a given location. A possible technique for rapid evaluation is one based on a system utilizing the "ground clutter" pattern seen on the radar (PPI) scope. <sup>16</sup>

#### Conclusion

This paper is considered a modest start in the direction of supplying irregular terrain propagation information applicable to systems engineering. The author encourages constructive criticism or the supply of data which may be beneficial for deriving better statistical data. For example, much data are required on frequencies above 1000 mc; the nature of the fine variations and their effects upon types of modulation; propagation data on vehicular-to-vehicular transmissions; good statistical small sector variation data; and so forth.

#### ACKNOWLEDGMENT

The author wishes to express his gratitude to all those referenced authors who have made this paper possible by their efforts in collecting propagation data.

<sup>15</sup> R. E. Lacy and C. E. Sharp, "Radar-type propagation survey experiments for communication systems," 1956 IRE CONVENTION RECORD, part 1, pp. 20–27.



# Design Theory for Depletion Layer Transistors\*

WOLFGANG W. GÄRTNER†, MEMBER, IRE

Summary-A new class of high-frequency transistors, the Depletion Layer Transistors (DLT), utilizes maximum attainable carrier velocities in solids by injecting electrons or holes into the high electric fields that prevail in properly designed depletion layers of reverse-biased p-n junctions. The resulting short transit times should insure operation up to microwave frequencies.

The design theory is presented for a particular example of a depletion layer transistor, discussing its low- and high-frequency, small-signal behavior, power gain, and stability. Other conceivable structures and modes of operation for DLT's are described and the potential importance of the depletion layer principle for solid-state microwave amplification is emphasized.

#### I. Introduction

ALASSICAL transistors are limited in their frequency response by either or both of two factors: the carrier transit time from the emitter to the collector junction, and the  $r_b/C_c$  product. Various advances in technology during the past few years have greatly reduced these two quantities, resulting in correspondingly higher operating frequencies. Further improvements, however, have become increasingly difficult, which led to the search for new principles that would obviate some of the basic limitations inherent in classical transistors. In a high-frequency transistor, the carrier transit time through the structure must be short compared to the reciprocal operating frequency, and no appreciable debunching of carrier pulses must occur during the transport process. The first requirement asks for high carrier velocity; i.e., high electric fields and, similarly, the second requirement may also be satisfied if the carriers travel in strong external fields compared to which the influence of diffusion and the carriers' own space charge is negligible. This concept forms the basic principle of a new class of high-frequency transistors known as Depletion Layer Transistors (DLT), which have recently been announced.1-4 Proper design of these devices will also keep internal RC combinations at very low values and operating frequencies up to the microwave range have been predicted.

\* Original manuscript received by the IRE, January 11, 1957; revised manuscript received July 1, 1957. A more detailed account of the design theory for depletion layer transistors is contained in USASEL Tech. Memo. No. M-1849; October, 1957.

† U. S. Army Signal Eng. Labs., Fort Monmouth, N. J.

<sup>1</sup> W. Gärtner, "A new uhf transistor structure," paper presented at WESCON Convention, Los Angeles, Calif.; August 21–24; 1956.

<sup>2</sup> W. Gärtner, F. A. Brand, and W. G. Matthei, "Design theory and exploratory development of the depletion layer transistor," paper presented at the PGED Second Annual Technical Meeting, Washington, D. C.; October, 1956. ington, D. C.; October, 1956.

<sup>3</sup> W. Gärtner, "Transistor physics," paper delivered before the Austrian Chem. and Phys. Soc., Vienna; January, 1957.

<sup>4</sup> W. Gärtner, "Transit time effects in depletion layer transistors," paper presented at the Symposium on the Role of Solid State Phenomeron in Floritie Circuits. Physics Layer Procedure. Procedure. nomena in Electric Circuits, Polytech. Inst., Brooklyn, Brooklyn, N. Y.; April, 1957.

# II. BASIC PRINCIPLE OF THE DLT

Very high electric fields may be created in the depletion layer (DL) of a reverse biased p-n junction, and when carriers are injected directly into this region, their transit time from the emitter to the collector side of the DL is very short (see Fig. 1). In fact, in properly designed depletion layers, carriers will reach the maximum velocity they can attain in solids under any conditions. If a design around this basic principle can be found with small-signal parameters that will give power gain, a response up to very high frequencies, possibly microwave, should be insured.

In the following five sections the design theory for a typical example of a depletion layer transistor is worked out in detail. Other conceivable realizations are discussed in Section VIII.

# III. STRUCTURAL MODELS, BASIC EQUATIONS, AND SMALL-SIGNAL SOLUTIONS

The derivation of the dc and ac current-voltage relationships will be carried out for the geometry and type of operation shown in Fig. 2. The analysis is one dimensional. It is expected to describe the essentials of operation although some of the proposed structures (see Fig. 3) may differ from this simple model. Emission into the depletion layer is assumed to occur from the "virtual emitter plane" indicated by a dashed line in Fig. 2: it may be realized physically by any kind of contact with the general characteristics described below. The current flow through the model structure is indicated in Fig. 4. The collector side has been assumed to be n type so that the active conduction current is carried by electrons which generally have a higher mobility and higher maximum velocity than holes. All of the following derivations are carried out for these doping conditions, and the results may be easily converted to the case of a p-type collector and holes as the active charge carriers.

The symbols in Fig. 4 have the following meanings:  $I_{1n}$  is the electron current flowing from emitter to collector,  $I_{1p}$  denotes the hole current flowing from emitter to base,  $I_{rev}$  is the current through the reverse biased p-n junction under zero emitter current conditions. In determining the dependence of these currents on the input and output voltages,  $V_1$  and  $V_2$ , we assume that small ac voltages,  $v_1$  and  $v_2$ , are superimposed on the dc voltages,  $V_{10}$  and  $V_{20}$ . The customary small-signal series expansion then yields for the emitter conduction current

$$I_{1,\text{cond}} = I_{1no} + i_{1n} + I_{1po} + i_{1p}$$

$$= I_{1no} + \eta_{n1}v_1 + \eta_{n2}v_2 + I_{1po} + \eta_{p1}v_1 + \eta_{2p \ 2}v \ (1)$$

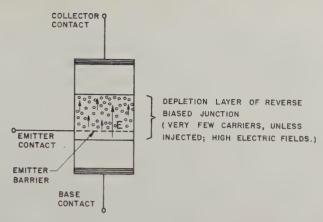


Fig. 1—Carriers injected directly into the depletion layer of a reverse biased *p-n* junction are swept towards the collector at high velocities.

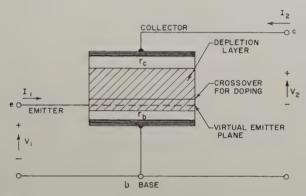


Fig. 2—One-dimensional model for geometrical structure of depletion layer transistor.

where

$$\eta_{i1} = (\partial I_{1i}/\partial V_1)_{V_2 = \text{const}}; \quad \eta_{i2} = (\partial I_{1i}/\partial V_2)_{V_1 = \text{const}}$$

and the other symbols have the meanings indicated in the list of symbols at the end of this paper.

Under the assumption that the transit time from emitter to collector is negligible at the frequencies considered, and that no recombination takes place between emitter and collector, the collector conduction current is the sum of the (voltage independent) junction reverse current,  $I_{co}$ , and the injected electron current,  $I_{1no}+i_{1n}$ ,

$$-I_{2,\text{cond}} = I_{co} + I_{1no} + \eta_{n1}v_1 + \eta_{n2}v_2.$$
 (2)

The input and output conduction currents are thus essentially determined by the dependence of the emitter injection current,  $I_{1,\text{cond}}$ , on the input and output voltages,  $V_1$  and  $V_2$ . For a mathematical description of the injection process and an evaluation of the  $\eta$ , another more specific assumption about the mechanism of carrier emission into the depletion layer must be made.

The simplest possibility—supported by experimental evidence—is that a barrier (this loose term is used de-

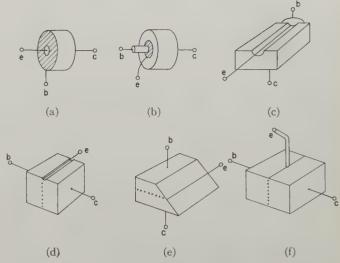


Fig. 3—Conceivable structures for depletion layer transistors (e, emitter; b, base; c, collector).

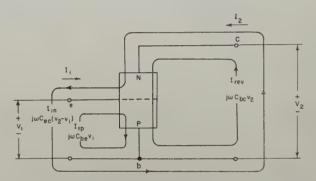


Fig. 4—Current flow through depletion layer transistor with p-type base and n-type collector.

liberately here because considerably more work is required to understand the physics of such contacts) exists between the emitter contact and the semiconductor material immediately underneath the contact, such that the emitter conduction current is given by

$$I_{1,\text{cond}} = I_{1n}(V_B) + I_{1p}(V_B) \simeq I_{1n}(V_{Bo}) + I_{1p}(V_{Bo}) + [(\partial I_{1n}/\partial V_B) + (\partial I_{1p}/\partial V_B)]v_B$$
 (3)

where  $V_{Bo} = V_{1o} - V_{so}$  and  $v_B = v_1 - v_s$ .

 $V_{so}$  and  $v_s$  are the dc and ac components, respectively, of the almost undisturbed potential in the semiconductor underneath the emitter contact. This means that the magnitude of the injected emitter current depends solely on the potential difference,  $V_B$ , between the emitter contact and the point in the depletion region immediately underneath it. As an example, we may consider an exponential characteristic,  $I_{1n}(V_B) = A_0$  [exp  $(\alpha V_B) - a$ ] from which  $(\partial I_{1n}/\partial V_B) = \alpha A_0$  exp  $(\alpha V_{Bo})$ . The following derivations, however, do not depend on the specific nature of this emission function. The potential,  $V_s = V_{so} + v_s$ , underneath the emitter contact is a certain fraction of the output voltage,

<sup>6</sup> G. L. Pearson, W. T. Read, W. Shockley, "Probing the space charge layer in a *p-n* junction," *Phys. Rev.*, vol. 85, p. 1055; March 15, 1952.

<sup>&</sup>lt;sup>5</sup> See in this connection C.-T. Sah, R. N. Noyce, and W. Shockley, "Carrier generation and recombination in *p-n* junctions and *p-n* junction characteristics," Proc. IRE, vol. 45, pp. 1228–1243, September, 1957.

$$V_{so} = \kappa_0(x) \times V_{2o}$$
 and  $v_s = \kappa_1(x, V_{2o}) \times v_2$ , (4)

the magnitude of which is determined by the impurity distribution across the junction, the position, x, of the emitter contact, and the applied dc bias.

In particular, the ac collector voltage feedback ratio,  $\kappa_1$ , is equal to  $(\partial \psi/\partial V_2)_{V_2}$ , where  $\psi(x)$  denotes the electrostatic potential across the depletion layer which may be calculated if the impurity distribution and applied dc voltage are known. Gain considerations, which will be discussed later, indicate that the voltage feedback ratio,  $\kappa_1$ , should be as small as possible and straightforward calculations on step junctions, graded junctions,  $p\pi n$ , pvn, and p-i-n junctions show that  $\kappa_1$  becomes smaller the closer the emitter contact can be placed to the base end of the depletion layer (and still be inside).

If we now substitute back into the original (1) and (2), we obtain for the conduction currents

$$I_{1,\text{cond}} \simeq I_{1no} + I_{1po} + (\partial I_{1n}/\partial V_B)(v_1 - \kappa_1 v_2)$$
  
  $+ (\partial I_{1p}/\partial V_B)(v_1 - \kappa_1 v_2)$  (5)

and

$$-I_{2,\text{cond}} \simeq I_{co} + I_{1no} + (\partial I_{1n}/\partial V_B)(v_1 - \kappa_1 v_2).$$
 (6)

In addition to these conduction currents, displacement currents will flow through the structure. Between any two contacts there will exist a capacitance C(V)which, in general, depends on the applied voltage,  $V = V_0 + v$ , but which may be assumed to be constant in a small-signal theory. The permissible values for the capacitances are determined by the desired gain and frequency response which will be discussed later. In view of the many conceivable geometries, the actual values of these capacitances shall not be calculated here, and we add a current  $j\omega C_{ee}(v_1-v_2)+j\omega C_{eb}v_1$  to the emitter conduction current and  $j\omega C_{ec}(v_2-v_1)+j\omega C_{bc}v_2$  to the collector conduction current where  $C_{ec}$ ,  $C_{eb}$ , and  $C_{bc}$  are the (ac-voltage independent) capacitances between emitter and collector, emitter and base, and base and collector leads, respectively.

Thus with (5) and (6) we find for the small-signal. four-pole admittances

$$y_{11} = \partial I_1 / \partial V_B + j\omega (C_{eb} + C_{ec}), \tag{7a}$$

$$y_{12} = -\kappa_1(\partial I_1/\partial V_B) - j\omega C_{ec}, \qquad (7b)$$

$$y_{21} = -\partial I_{1n}/\partial V_B - j\omega C_{ec}, \tag{7c}$$

$$y_{22} = \kappa_1 (\partial I_{1n} / \partial V_B) + j\omega (C_{cb} + C_{ec}). \tag{7d}$$

An equivalent circuit for the "intrinsic" device as characterized by (7) is shown in Fig. 5. The emitter and the collector branch each contain a current source as indi-

The currents through the device will be somewhat modified by the impedances of the bulk material on both sides of the junction,  $r_b$  (base series impedance), and  $r_c$  (collector series impedance) and by the leakage conductance, g<sub>s</sub>, across the junction. These, however,

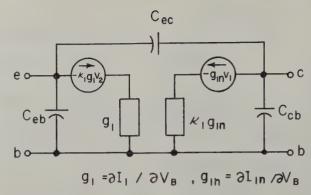


Fig. 5-Equivalent circuit for "intrinsic" DLT in common base configuration.

may easily be taken into account by simple four-pole transformations (a situation similar to the inclusion of the base spreading resistance in ordinary transistors). For optimum performance, all these quantities should be kept small.

Eq. (7) shows that the magnitude of the small-signal, four-pole admittance depends on the capacitances between the contacts, on the nature of the emission function (for which an exponential behavior was given above as an example), on the emitter efficiency; i.e., on the fraction of total emitter current carried by electrons, and finally on the ac voltage feedback ratio,  $\kappa_1$ . In particular, the output admittance,  $y_{22}$  is by a factor  $\kappa_1$  (for negligible capacitance effects) smaller than the input admittance (since  $\kappa_1 \leq 1$  always), and the ratio between them is the source of ac power gain in this device which, without carrier multiplication, has a current gain of not more than unity.

The exact dependence of power gain on these various quantities is analyzed in Section VII.

#### IV. CALCULATION OF TRANSIT TIME

To determine whether the assumption of negligible transit time,  $\tau$ , from emitter to collector is justified at the frequency of operation or whether a more elaborate theory should be used, a calculation of the transit time

$$\tau = \int_{r_0}^{x_c} \frac{dx}{u} \tag{8}$$

must be carried out, where  $x_e$  and  $x_c$  are the coordinates of the emitter and collector, respectively, and u(x) is the carrier velocity the field dependence of which has been investigated by Ryder, et al.7 At low fields the velocity is proportional to the electric field, at higher fields it is proportional to only  $E^{1/2}$ , and finally it reaches

<sup>7</sup> E. J. Ryder and W. Shockley, "Mobilities of electrons in high electric fields," *Phys. Rev.*, vol. 81, p. 139; January, 1951.
W. Shockley, "Hot electrons in germanium and Ohm's law," *Bell Sys. Tech. J.*, vol. 30, p. 990; October, 1951.
E. J. Ryder, "Mobility of holes and electrons in high electric fields," *Phys. Rev.*, vol. 90, p. 766; June, 1953.
E. M. Conwell, "High field mobility in germanium with impurity scattering dominant," *Phys. Rev.*, vol. 90, p. 764; June, 1953, and "Mobility in high electric fields," *Phys. Rev.*, vol. 88, p. 1379; December, 1952. December, 1952.

a maximum constant (field independent) value which is: e.g., approximately  $6 \times 10^6$  cm seconds<sup>-1</sup> for electrons in germanium, and 8×106 cm seconds-1 for electrons in silicon at room temperature. Using the published data.<sup>7</sup> (8) may be easily integrated. From the impurity distribution across the junction, the electric field is first calculated as a function of distance across the depletion layer, which is then divided into regions where the carrier velocity varies like E,  $E^{1/2}$  or is field-independent, and integral (8) is evaluated in each of these regions, the extension of which depends on the material used, on the impurity distribution, and on whether the active carriers are holes or electrons.

To obtain the desired short transit times, high fields are advantageous. They should, however, lie below the critical voltage for avalanche breakdown8 which varies for different materials. Utilizing controlled carrier multiplication, on the other hand, may be a desirable mode of operation for this device (see Section V).

The most advantageous case is obviously the one where the carriers have their maximum velocity throughout the entire depletion layer. This can be accomplished by sandwiching a lightly doped region between two heavily doped regions of different conductivity type and applying such a voltage that the (nearly constant) field throughout the middle layer lies above the critical field for constant carrier velocity and below the avalanche breakdown threshold. Under these conditions an electron in germanium; e.g., will traverse a distance of 10<sup>-3</sup> cm which may be a typical value for the depletion layer thickness in  $1.7 \times 10^{-10}$  seconds.

#### V. CARRIER MULTIPLICATION

If carrier multiplication occurs in the depletion layer, the current amplification will exceed unity and, therefore, this condition is of considerable interest. Here we shall analyze the case where the injected carriers are multiplied by a factor m in the region between emitter and collector.9 This can be achieved by designing the impurity distribution around the doping crossover in such a way that the electric field exceeds the critical

<sup>8</sup> K. G. McKay, and K. B. McAfee, "Electron multiplication in silicon and germanium," *Phys. Rev.*, vol. 91, p. 1079; September 1,

K. G. McKay, "Avalanche breakdown in silicon," Phys. Rev., vol. 94, p. 877; May 15, 1954.
P. A. Wolff, "Electron multiplication in silicon and germanium," Phys. Rev., vol. 95, p. 1415; September 15, 1954.
S. L. Miller, "Avalanche breakdown in germanium," Phys. Rev., vol. 99, p. 1234; August 15, 1955.

E. Groschwitz, "Zur stossionisation in silizium und germanium," Z. Phys., vol. 143, p. 632; January, 1956.

Compare also in this connection A. G. Chynoweth and K. G.

McKay, "Internal field emission in silicon p-n junctions," Phys. Rev., vol. 106, p. 418; May 1, 1957.

<sup>9</sup> At the AIEE-IRE Semiconductor Devices Res. Conf., Purdue Univ., Lafayette, Ind., June 25 to 27, 1956, H. Statz and R. A. Pucel discussed a very high-frequency device which utilizes avalanche

effects in the depletion region.

The use of controlled avalanche in conventional transistors has been described by S. L. Miller and J. J. Ebers, "Alloyed junction avalanche transistors," *Bell Sys. Tech. J.*, vol. 34, p. 883; September, 1955, where additional references on carrier multiplication in semiconductors may be found.

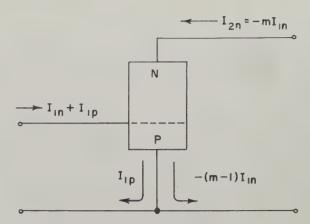


Fig. 6—Distribution of active conduction currents for case of carrier multiplication in emitter-collector region.

value for multiplication.8 The conduction current flow under these circumstances is shown in Fig. 6 under the assumption that due to proper geometry or magnetic fields<sup>10</sup> none or only a few of the internally created carriers are captured by the emitter contact. Then the emitter current will be unchanged and the collector conduction current is multiplied by the factor m. The new dc collector current is then given by

$$-I_{2o} = I_{com} + mI_{1no} (9)$$

and the new ac four-pole parameters are of the following form:

$$y_{11} = \partial I_1/\partial V_B + j\omega(C_{eb} + C_{ec}). \tag{10a}$$

$$y_{12} = -\kappa_1(\partial I_1/\partial V_B) - j\omega C_{ec}. \tag{10b}$$

$$y_{21} = -m(\partial I_{1n}/\partial V_B) - j\omega C_{ec}. \tag{10c}$$

$$y_{22} = m\kappa_1(\partial I_n/\partial V_B) + j\omega(C_{cb} + C_{ec}) - (I_{co} + I_{1no})(\partial m/\partial V_2).$$
(10d)

The last term in (10d) describes the modulation of the dc current through the structure by variations of the multiplication ratio as a function of output voltage. This effect reduces the output impedance and should be kept low. The details of designing a localized multiplication region will be the subject of a later publication.

From (10) it is apparent that multiplication will increase the output admittance, possibly above the input admittance (depending on  $\kappa_1$  and m), and the mechanism of power gain in this case is by current amplification rather than through the admittance ratio.

#### VI. TRANSIT TIME EFFECTS

Of particular interest in any high-frequency device is its upper limit of operating frequency which the above simple low-frequency design theory is unable to predict. We shall, therefore, now discuss the case in which the transit time is no longer negligible as compared to the reciprocal frequency. A phase difference between emitter and collector conduction currents will then occur,

<sup>10</sup> Suggestion of F. A. Brand of Signal Corp. Eng. Labs., Fort Monmouth, N. J.

and several or many cycles of conduction current may be in transit through the structure simultaneously. The advantage of this type of operation—if it resulted in power gain-would evidently be that for a given frequency the width of the depletion layer could be larger than for the case in which the transit time must be negligible. This would result in greater ease of construction and reduction in capacitance, both of which factors would contribute to a higher ultimate operating frequency for DLT's.

A derivation of the small-signal admittances under these conditions, carried out in Appendix I, leads to

$$y_{11} = g_{1n}/\varphi \tag{11a}$$

$$y_{11} = g_{1n}/\varphi$$
 (11a)  
$$y_{12} = -\frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi}$$
 (11b)

$$y_{21} = -\frac{g_{1n}}{\varphi} - j\omega \frac{\epsilon A}{w_1 + w_2} \frac{g_{1n}\phi}{\varphi}$$
 (11c)

$$y_{22} = \frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi} - j\omega \frac{\epsilon A}{w_1 + w_2} \frac{1}{\varphi}$$
 (11d)

where

$$\phi = \frac{w_2^2}{\epsilon A u} \frac{e^{-j\omega w_2/u} - 1 + j\omega w_2/u}{(\omega w_2/u)^2}$$
 (12a)

$$\phi = 1 + \frac{w_1}{w_1 + w_2} g_{1n} \phi. \tag{12b}$$

Terms resulting from the influence of parasitics mentioned in earlier sections (capacitances, series, and shunt impedances) may be added to these characteristics of the "intrinsic" transistor.

The influence of transit time is described by the function  $\phi$  (12a) while  $\varphi$  is practically equal to unity in most cases.  $\phi$  possesses a strong frequency dependence as shown in Fig. 7 where  $(e^{-\tau\omega i}-1+j\omega\tau)/(\omega\tau)^2$  with  $\tau = w_2/u$  has been plotted vs  $\omega \tau$ . As will be seen in Section VII, it causes the power gain to decrease rapidly as soon as the frequency becomes comparable to the reciprocal transit time, 11 an effect quite analogous to the transit time phenomena in electron tubes. Unless multiplication or another scheme of ac conduction current amplification is utilized, the structures must be designed to keep the transit time below one period of the particular frequency.

# VII. GAIN AND STABILITY OF THE DLT

The investigation of the gain question for the DLT is complicated by the fact that the "intrinsic" DLT as characterized by (7) is potentially unstable<sup>12</sup> at all ex-

11 The author owes an illuminating discussion on this subject to H. Krömer of RCA.

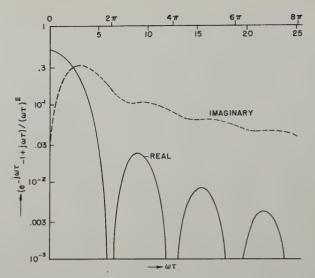


Fig. 7— $(e^{-j\omega\tau}-1+j\omega\tau)/(\omega\tau)^2$  plotted as a function of  $\omega\tau$ .

cept very high frequencies. Parasitic influences such as mentioned in Section III will reduce the power gain and may even make the device unconditionally stable. The pertinent derivations are straightforward but lengthy and shall not be given here. Rather, we shall first discuss the gain of the "intrinsic" DLT and then investigate its stability behavior. To characterize power gain, we use the ratio of the power,  $N_L$ , delivered into a matched load,  $Y_L$ , over the power,  $N_i$ , delivered into the input of a transistor:

$$\frac{N_L}{N_i} = \frac{-y_{21}y_{21}^*}{(y_{11} + y_{11}^*)(y_{22} + y_{22}^*) - (y_{21}y_{12} + y_{21}^*y_{12}^*)}. (13)$$

The asterisk denotes the complex conjugate. If we first consider the case of negligible transit time, we find from

$$\frac{N_L}{N_i} = \frac{g_{1n}^2 + \omega^2 C_{ee}^2}{2\kappa_1 g_{1g_{1n}} + 2\omega^2 C_{ee}^2}$$
(14)

where  $g_1 = \partial I_1 / \partial V_B$  and  $g_{1n} = \partial I_{1n} / \partial V_B$ . This expression permits us to draw conclusions as to the design which will give high power gain: the emitter-collector capacitance,  $C_{ec}$ , shall be as small as possible;  $\kappa_1$ , the ac voltage feedback ratio shall be as small as possible [at low frefrequencies the power gain is actually given by  $1/(2\kappa_1)$ for unit emitter efficiency]; the ac emitter efficiency shall be as close to one as possible so that  $g_{1n} \sim g_1$ .

 $C_{ec}$  is kept low by small area contacts and wide separation of emitter and collector; values in the range of a few tenths of a μμf as they are known from microwave diodes should be realizable.  $\kappa_1$ , as pointed out earlier, must be kept low by placing the effective emitter contact13 very close to the base end of the depletion layer, at least within 1/10 of the total depletion layer thick-

<sup>12</sup> For a discussion of the problems of maximum available gain and stability in an active four-pole, see J. G. Linvill, "The relationship of transistor parameters to amplifier performance," paper presented at the IRE-AIEE, University of Pennsylvania Conference on Transistor Circuits, Philadelphia, Pa., February 17, 1955; for further references see R. L. Pritchard, "Measurement considerations in high-frequency power gain of junction transistors," Proc. IRE, vol. 44, pp. 1050-1051; August, 1956.

<sup>13</sup> The "effective" emitter contact may be the small forward biased portion of a larger contact, the rest of which is reverse biased with respect to the underlying depletion layer with its steep potential gradient.

ness. Emitter contacts with essentially unit efficiency can be made.<sup>2,14</sup> Thus for a depletion layer thickness of  $3 \times 10^{-3}$  cm in germanium and an optimum transit time (p-i-n junction) of  $5 \times 10^{-10}$  second, a  $\kappa_1$  of 0.05 (location of effective emitter contact within  $1.5 \times 10^{-4}$  cm of base end of DL), an emitter-collector capacitance,  $C_{ec}$  of 0.1  $\mu\mu$ f, and a value of  $g_1$  of  $10^{-2}$  mho, one finds from (14) a power gain of 10 db at 1000 mc/seconds. With the advent of more refined techniques which allow a closer control of small dimensions, an improvement in the maximum frequency of DLT's with negligible transit time may be expected. Similarly, if other semiconductors are found which have a higher maximum carrier velocity (this property has so far only been investigated in germanium and silicon) higher frequency cutoff will result.

If we consider the case of controlled carrier multiplication, we obtain with (10)

$$\frac{N_L}{N_i} = \frac{m^2 g_{1n}^2 + \omega^2 C_{ec}^2}{2\kappa_i m g_1 g_{1n} + 2\omega^2 C_{ec}^2 - 4g_1 (I_{co} + I_{1no}) (\partial m/\partial V_2)}$$
(15)

Neglecting capacitances and the last term in the denominator, we find that the power gain will increase by a factor of m. In addition, because of the reduction in output impedance, the capacitances become less critical. Similarly, and maybe most important at the present time,  $\kappa_1$ ; i.e., the position of the emitter contact, is no longer the major gain-determining factor. In other words, the emitter contact may be anywhere in the depletion layer as long as only few carriers return to it (which must be avoided by proper structures or magnetic fields<sup>10</sup>) and a power gain of at least a value of mmay be realized as long as capacitances and the ac modulation of the dc current through the junction are negligible. With these relaxed requirements on geometrical control in the structure, substantial power gains in the 10,000 mc range appear feasible because it is possible with existing techniques to locate a contact somewhere inside a  $1\mu$  depletion layer which possesses a transit time of the order of 2×10<sup>-11</sup> seconds under optimized conditions (p-i-n junction). The upper limit on the permissible multiplication factor is imposed by the condition that the space charge of the mobile carriers must remain negligible in the depletion layer. Internal RC combinations which also limit the frequency response of classical transistors can be kept negligibly small by reducing the series resistance of the bulk material on either side of the depletion layer.

We have thus shown that on the basis of designs with negligible transit time, power gain up to the microwave region is possible. Other potential applications of the device include uhf and microwave oscillators and extremely fast switches. We now want to investigate the frequency dependence of power gain when the transit

Fig. 8—The function  $|(e^{-j\omega\tau}-1)/(j\omega\tau)|^2$  plotted vs  $\omega\tau$ .

time becomes comparable to one period. Substituting (11) into (13), one obtains under the assumption of  $\varphi \simeq 1$  and  $w_2 \simeq w$ 

$$\frac{N_L}{N_i} = \frac{-g_{1n}^2 \left| (e^{-j\omega\tau} - 1)/(j\omega\tau) \right|^2}{(w_1/w)g_{1n}^2 [4 - 2(\sin\omega\tau)/(\omega\tau)]} \cdot$$
(16)

Eq. (16) shows that even when the capacitances may be neglected, the power gain drops off with frequency as  $|(e^{-j\omega\tau}-1)/(j\omega\tau)|^2$  which is shown in Fig. 8. It thus does not appear feasible to raise the frequency to much above twice the reciprocal transit time unless very high gain is available at lower frequencies which may be sacrificed in this cutoff tail and still give sufficient amplification at frequencies higher than the cutoff frequency.

The question of stability of a DLT may be analyzed with the help of Fig. 9. It shows the stable and unstable regions for the external admittances,  $Y_S$  and  $Y_L$ , of an active four-pole, and has been derived in Appendix II. If the external conductances are chosen to lie in the area where the two regions which are bounded by hyperbolas and straight lines, respectively, overlap, then oscillations without external feedback will result. Outside this area the device is stable. If the two regions do not overlap, which occurs for

$$| 2 \operatorname{Re} (y_{11}) \operatorname{Re} (y_{22}) - \operatorname{Re} (y_{12}y_{21}) | < | y_{12}y_{21} |$$
 (17)

the device is unconditionally stable. If we now apply these considerations to the "intrinsic" DLT with negligible transit time, (7), we find that condition (17) is never satisfied; *i.e.*, that the two regions in Fig. 9 will always overlap. To determine the external admittances for which the DLT will oscillate at a certain frequency without external feedback, one thus draws a diagram like Fig. 9 for the particular frequency, and selects a pair of values for the real parts of the admittances from the doubly shaded region, and then calculates the corresponding imaginary parts from (35) and (36) in Appendix II. If stable amplifier operation is desired, one selects a pair of admittances outside the doubly shaded

<sup>&</sup>lt;sup>14</sup> W. G. Matthei and F. A. Brand, "On the injection of carriers into a depletion layer," J. Appl. Phys., vol. 28, p. 513; April, 1957.

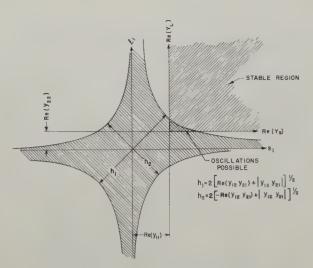


Fig. 9—Stable and unstable regions for external admittances between terminals of active four-pole.

region. To investigate the stability behavior over a frequency band, one would have to construct a three-dimensional scheme with the frequency as the third co-ordinate.

The same remarks essentially hold for the multiplication case, at least as long as the last term in (10d) is negligible. An investigation of the stability behavior based on the frequency dependent four-pole admittances of (11) leads to a complicated transcendental equation from which it is fairly easy to determine whether the device will oscillate at a given frequency. The calculation of the exact cutoff frequency, however, is difficult and would exceed the scope of this discussion.

With these remarks, we want to close the section on gain and stability because this paper deals mainly with the design theory of the device and not its circuitry. The main object of Section VII was to establish that the device described is indeed an active four-pole capable of power gain.

#### VIII. OTHER DLT DESIGNS

In this section a number of DLT-type structures are mentioned, which appear feasible and illustrate the prediction that designs around the principle of carrier transport through high field depletion layers will play a similar role in very high-frequency solid-state amplification, as structures based on carrier diffusion do at lower frequencies. No mathematical analysis of these proposed devices shall be given in this paper.

It has been shown that for a regular DLT with no carrier multiplication the ac current amplification drops off rapidly when the transit time is comparable to one period. Higher frequency response thus requires narrower depletion layers. It has also been shown that the problem of properly locating the emitter contact in the narrow DL to keep the ac voltage feedback small may be circumvented by boosting the current amplification through controlled carrier multiplication.

A similar principle may be applied to a structure where the transit time is equal to several periods of the operating frequency. If, namely, a narrow region near the collector end of the depletion layer contains multiplying fields which offset the frequency-determined reduction in current amplification, then operation beyond the natural cutoff frequency appears feasible. The multiplied carriers of opposite sign must be prevented from returning to the emitter contact; this can be accomplished in several different ways: one may consider the amplification of pulses where the emitter is forward biased only during the duration of the pulse and reverse biased at all other times so that it will not collect carriers of the opposite sign. This device will show a certain delay between signal pulse and amplified pulse due to the transit time from the emitter contact to the multiplying region which, in itself, may find an application. When cw operation is desired, a magnetic field may be used to divert the returning carriers from the emitter contact. This type of operation resembles the "dissected amplifier" idea with the gyrating element built into the device close to the amplifying region. 15

Another interesting modification of the basic DLT principle would be a device where the carriers are generated inside the DL by modulated light or microwave energy, or where the multiplication factor m is modulated by the microwave field parallel or perpendicular to the junction. In devices like this, the transition is found from amplification by principles at least vaguely related to transistor operation and amplification utilizing other solid-state phenomena.

It may also prove to be of great interest to investigate the properties of depletion layers at low temperatures where the maximum carrier velocities<sup>7</sup> and the mean free path of the carriers increase.

#### IX. CONCLUSION

The experimental phase of the development of the device is well underway and has been partially reported. In particular, it has been shown that the injection into the depletion layer occurs as assumed in the theory and that the low-frequency gain depends on the voltage feedback ratio,  $\kappa_1$ , in the predicted manner. When more complete information is available, the design theory may be refined and generalized in many obvious ways. At that time also the noise problem may be attacked.

## APPENDIX I

CALCULATION OF THE FOUR-POLE PARAMETERS OF A DLT UNDER TRANSIT TIME CONDITIONS

In the first paper on the design theory of the proposed devices, the effects of transit time will be analyzed under the simplest assumptions. The many conceivable

<sup>15</sup> W. Shockley and W. P. Mason, "Dissected amplifiers using negative resistance," J. Appl. Phys., vol. 25, p. 677; May, 1954.

generalizations shall be carried out when more experimental information is available. We thus assume: 1) All ac quantities, a, may be expressed by  $a=a_0 \exp(j\omega t)$  where  $a_0$  is complex; 2) only electrons are injected which carry the entire ac conduction current,  $i_n(x, t)$ ; 3) the virtual emitter has no other electrical influence than the emission of carriers; 4) the carriers move with a high, field-independent, constant velocity, u, and no "debunching" of the carrier waveform occurs due to either diffusion or the electron space charge; 5) the analysis applies to a p-i-n structure with highly doped p and p regions. Such a junction is well simulated by a plane parallel capacitor. The width, p0, of the depletion layer is then assumed independent of ac voltage.

The derivation is based on the geometry of Fig. 10. The injected electron current depends on the voltage  $V_B = V_1 - V_s$ , where  $V_s$  is the potential inside the DL underneath the emitter junction.  $V_s$  is given by

$$V_s = \int_{-w_1}^0 E(x, t) dx = E(-w_1, t) \times w_1$$
 (18)

or

$$V_s = V_2 - \int_0^{w_2} E(x, t) dx.$$
 (19)

In the region  $-w_1 < x < 0$ , E is independent of distance,  $E = E(-w_1, t)$ , because of the absence of any space charge, whereas in the range of  $0 < x < w_2$  it is equal to

$$E(x,t) = E(-w_1,t) + (1/\epsilon) \int_0^x \rho(x,t) dx.$$
 (20)

As we are mainly interested in the linearized ac parameters (the dc relationships are identical with those of Section III), we separate the small ac part from the dc part and find for (18) and (19)

$$v_s = E_{AC}(-w, t) \times w_1 \tag{21}$$

and

$$v_{s} = V_{2} - E_{AC}(-w_{1}, t) \times w_{2} + \frac{i_{1n}u}{\epsilon A\omega^{2}} (e^{-j\omega w_{2}/u} - 1) + j\frac{i_{1n}w_{2}}{\epsilon A\omega}$$
(22)

where  $(Au)^{-1} \times i_n(x, t) = (Au)^{-1} \times i_{1n}(t-x/u)$  has been substituted for the ac variations of the space charge,  $\rho_{AC}$ . Substituting  $E_{AC}$  from (21) into (22) thus yields

$$v_s = [w_1/(w_1 + w_2)](v_2 + i_{1n}\phi) \tag{23}$$

where

$$\phi = \frac{w_2^2}{\epsilon A u} \frac{e^{-j\omega w_2/u} - 1 + j\omega w_2/u}{(\omega w_2/u)^2} \cdot \tag{24}$$

With (23) and

$$i_{1n} = (\partial I_{1n}/\partial V_B)v_B = g_{1n}v_B \tag{25}$$

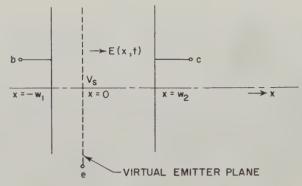


Fig. 10—Geometry for the analysis of transit time effects in the DLT.

one finds

$$i_{1n} = \frac{g_{1n}}{\varphi} v_1 - \frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi} v_2 \tag{26}$$

with

$$\varphi = 1 + \frac{w_1}{w_1 + w_2} g_{1n} \phi. \tag{27}$$

Since the conduction current is delayed by  $w_2/u$  on its way from emitter to collector, one obtains for the ac collector electron current

$$-i_{2n}(t) = i_{1n}(t - w_2/u)$$

$$= \frac{g_{1n}}{\varphi} \left( e^{-j\omega w_2/u} \right) v_1 - \frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi} \left( e^{-j\omega w_2/u} \right) v_2. \tag{28}$$

According to (20),  $i_{1n}$  is the total emitter current. The total collector current, however, is the sum of  $i_{2n}$  and the displacement current

$$-i_{2,\text{disp}} = \epsilon A \frac{\partial E(w_2, t)}{\partial t}$$

$$= j\omega \frac{\epsilon A}{w_1 + w_2} \left[ \frac{g_{1n}\phi}{\varphi} v_1 + \left( 1 - \frac{w_1}{w_1 + w_2} \frac{g_{1n}\phi}{\varphi} v_2 \right) + i_{1n}(1 - e^{-j\omega w_2/u}).$$
(29)

The first term in (29) is the capacitive current between base and collector, the second compensates for the phase shift in conduction current.

From (26), (28), and (29) it is thus possible to calculate the small-signal, four-pole admittances  $y_{ik}$ :

$$y_{11} = g_{1n}/\varphi \tag{30a}$$

$$y_{12} = -\frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi}$$
 (30b)

$$y_{21} = -\frac{g_{1n}}{\varphi} - j\omega \frac{\epsilon A}{w_1 + w_2} \frac{g_{1n}\phi}{\varphi}$$
 (30c)

$$y_{22} = \frac{w_1}{w_1 + w_2} \frac{g_{1n}}{\varphi} - j\omega \frac{\epsilon A}{w_1 + w_2} \frac{1}{\varphi}$$
 (30d)

#### APPENDIX II

CALCULATION OF THE CONDITIONS FOR UNCONDITIONAL STABILITY OR SELF-EXCITATION OF AN ACTIVE FOUR-POLE

An active four-pole, the input of which is passively terminated by the admittance,  $Y_S$ , and the output of which is passively terminated by an admittance,  $Y_L$ , will oscillate if the condition<sup>16</sup>

$$\Delta = \begin{vmatrix} y_{11} + Y_s & y_{12} \\ y_{21} & y_{22} + Y_L \end{vmatrix}$$
 (31)

is satisfied. Eq. (31) is equivalent to the following relationships:

$$s_1 l_1 - s_2 l_2 = a (32)$$

and

$$s_1 l_2 + s_2 l_1 = b (33)$$

where

$$s_1 = \text{Re } (y_{11} + Y_8), \quad s_2 = \text{Im } (y_{11} + Y_8)$$
  
 $l_1 = \text{Re } (y_{22} + Y_L), \quad l_2 = \text{Im } (y_{22} + Y_L)$   
 $a = \text{Re } (y_{12}y_{21}), \qquad b = \text{Im } (y_{12}y_{21}).$  (34)

Eqs. (32) and (33) permit us to determine the values of  $Y_S$ ,  $Y_L$  for which the four-pole will oscillate at a given frequency. For this purpose, we derive a solution of (32) and (33) for which  $s_1$ ,  $s_2$ ,  $l_1$ ,  $l_2$  are all real and Re  $(Y_S) > 0$ , Re  $(Y_L) > 0$ . We find

$$s_2 = \left\{ b \pm \left[ b^2 - 4(s_1^2 l_1^2 - a s_1 l_1) \right]^{1/2} \right\} / (2l_1)$$
 (35)

and

$$l_2 = \left\{ b \mp \left[ b^2 - 4(s_1^2 l_1^2 - a s_1 l_1) \right]^{1/2} \right\} / (2s_1)$$
 (36)

 $s_2$  and  $l_2$  may be positive or negative, but must be real which leads to the condition

$$s_1^2 l_1^2 - a s_1 l_1 - b^2 / 4 \le 0. (37)$$

Eq. (37) states that the permissible values on the  $s_1 - l_1$  plane lie within the area bounded by the two hyperbolas

$$2s_1 l_1 = a + (a^2 + b^2)^{1/2}$$
= Re  $(y_{12}y_{21}) + |y_{12}y_{21}|$  (38)

<sup>16</sup> See, e.g., H. W. König, "Laufzeittheorie der Elektronenröhren," Springer Verlag, Vienna; 1948. The discussion in the present paper is an adaptation of the methods developed by König which also contain stability criterion of Linvill (op. cit.) in implicit form.

and

$$2s_1 l_1 = a - (a^2 + b^2)^{1/2}$$
= Re  $(y_{12}y_{21}) - |y_{12}y_{21}|$  (39)

which is shown in Fig. 9. We now transform back according to (34)

$$Re(Y_S) = s_1 - Re(y_{11})$$
 (40)

$$Re(Y_L) = l_1 - Re(y_{22})$$
 (41)

which shifts the coordinate axes as indicated in Fig. 9. Since Re  $(Y_S)$  and Re  $(Y_L)$  must be positive, only those values of Re  $(Y_L)$  and Re  $(Y_S)$  will give oscillations which lie in the region where the positive quadrant of the Re  $(Y_S)$  – Re  $(Y_L)$  plane overlaps the area bounded by the hyperbolas (see Fig. 9). Outside this region, the four-pole is stable. If the positive quadrant does not intersect the hyperbolas at all, which occurs for

 $| 2 \text{ Re } (y_{11}) \text{ Re } (y_{22}) - \text{Re } (y_{12}y_{21}) | < | y_{12}y_{21} |$ , (42) the device is unconditionally stable.

# LIST OF SYMBOLS OTHER THAN DEFINED IN THE TEXT

A =conducting cross section of transistor.

 $E_{AC}$  = ac part of electric field strength.

 $I_{com}$  = dc reverse current under multiplication conditions.

 $I_{1no}$  = dc emitter electron current.

 $I_{1po} = dc$  emitter hole current.

 $i_{1n}$  = ac emitter electron current.

 $i_{1p}$  = ac emitter hole current.

 $j=\sqrt{-1}$ .

 $N_a$  = acceptor concentration.

 $N_d$  = donor concentration.

q = electron charge.

 $w = w_1 + w_2 = \text{total}$  width of depletion layer.

 $\epsilon$  = dielectric constant.

 $\rho$  = electric charge density.

 $\rho_{ac}$  = ac part of electric charge density.

 $\tau$  = transit time from emitter to collector.

 $\omega = \text{circular frequency}.$ 

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# A Note on Numerical Transform Calculus\*

RUBIN BOXER†, MEMBER, IRE

Summary-Many of the numerical transform methods, developed for the solution of integrodifferential equations, exhibit difficulties when discontinuities occur at the origin. In this paper a procedure for including initial conditions is derived which effectively takes origin discontinuities into account.

Although shown to be applicable to a number of transform methods, the derivation emphasizes application to the z-form integration operators because of their relatively greater accuracy.

Numerical examples illustrating the solution of a constant coefficient and a time-varying problem are given. The technique is equally applicable to the solution of nonlinear problems.

#### Introduction

URING recent years a number of numerical techniques have been developed in operational form which systematize the obtaining of solutions to linear and nonlinear integrodifferential equations.1-8

Tustin, operating in the time domain completely, developed a set of integration operators. He showed that given a function y(t), defined at the points y(0), y(T), y(2T),  $\cdot \cdot \cdot$ , the difference equation representation for the first integral of y(t)

$$\frac{T}{2}i_1(t+T) - \frac{T}{2}i_1(t) = \frac{T}{2}y(t+T) + \frac{T}{2}y(t) \quad (1)$$

could be put into operational form. A convenient notation, which will be used in this paper, is the z transform. Using this notation, the transfer function for (1) is:

$$\frac{I_1(z)}{Y(z)} = \frac{T}{2} \frac{z+1}{z-1} \cong \frac{1}{p} . \tag{2}$$

Here 1/p represents the integration operator and

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† Servomechanisms, Inc., Westbury, N. Y.; formerly with Rome Air Dev. Ctr., Rome; N.Y.

1 A. Tustin, "A method analyzing the behavior of linear systems in terms of time series," and "A method of analyzing the effects of certain kinds of non-linearity in closed-cycle control systems," (Proceedings of the Convention on Automatic Regulators and Servo-

mechanisms) vol. 94, Part II-A, p. 130 ff.; May, 1947.

<sup>2</sup> A. Madwed, "Number Series Method of Solving Linear and Nonlinear Differential Equations," M.I.T. Instr. Lab. Rep. No.

6445-T-26; April, 1950.

<sup>2</sup> J. G. Truxal, "Numerical analysis for network design," IRE TRANS., vol. CT-1, pp. 49-60; September, 1954.

<sup>4</sup> R. Boxer and S. Thaler, "A simplified method of solving linear and nonlinear systems," PROC. IRE, vol. 44, pp. 89-101; January,

and nonlinear systems," PROC. IRE, vol. 44, pp. 89–101; January, 1956.

<sup>5</sup> S. Thaler and R. Boxer, "An operational calculus for numerical analysis," 1956 IRE CONVENTION RECORD, part 2, pp. 100–105.

<sup>6</sup> S. Amarel, L. Lambert, and J. Millman, "A Transformation Calculus for Obtaining Approximate Solutions to Linear Integro-Differential Equations with Constant Coefficients," Columbia Univ. Electronics Res. Labs. Tech. Rep. T-7/C; August, 1954.

<sup>7</sup> S. Amarel, "A Computational Method for Treating Networks Containing Nonlinear Elements," Columbia Univ. Electronics Res. Labs., Tech. Rep. T-3/C; August, 1954.

<sup>8</sup> S. Amarel, "An Operational Method for the Treatment of Transients in Waveform Circuits (Linear and Nonlinear)," Columbia Univ. Electronics Res. Labs., Tech. Rep. T-5/C; April, 1955.

 $z = e^{sT}$ . Eq. (2) is equivalent to the transfer function for trapezoidal integration originally derived in z-transform notation by Salzer.9

Tustin further proposed that higher order integrating operators could be given by:

$$\frac{1}{p^k} \cong \left(\frac{T}{2} \frac{z+1}{z-1}\right)^k. \tag{3}$$

Tustin's procedure works well, but has difficulty when the time functions operated on, or their derivatives. are not zero at the zero instant of time.

Madwed<sup>2</sup> improved upon the method of Tustin by developing integrating operators of greater accuracy in addition to introducing a fairly complex procedure for operating upon discontinuous functions. The first order integration operator of Madwed is identical to that of (2), but the higher order operators differ, and as stated above, are more accurate. For example, the second-order integrating operator of Madwed is

$$\frac{1}{p^2} \cong \frac{T^2}{6} \frac{z^2 + 4z + 1}{(z - 1)^2} \,. \tag{4}$$

The simplification of Madwed's notation to that of the z transform was included in a paper by Truxal.3

Thaler and this author<sup>4-5</sup> used the frequency domain to demonstrate that it is possible to substitute integration operators, considered from a Laplace transform viewpoint, into the Laplace transforms of linear and nonlinear equations. The derived operators were termed z forms. For example, the z-form operator for  $1/s^2$  is

$$\frac{1}{s^2} \cong \frac{T^2}{12} \frac{z^2 + 10z + 1}{(z - 1)^2}$$
 (5)

In a recent report<sup>10</sup> the greater accuracy of the z forms was demonstrated and a method for calculating error was supplied. Table I lists the z forms for  $1/s^k$ , together with corresponding z transforms. The z transforms are shown in Table I to illustrate their relationship to the z forms. Table II illustrates the relative accuracies of the various integrating operators. Note that when the z transform is to be used as an integrating operator, it is multiplied by T.

The z-form method had a disadvantage. In order to obtain the full accuracy inherent in the operators, the time functions and their derivatives had to be of zero value at the time origin. To accomplish this in certain problems required a change of variable which, at times.

J. M. Salzer, "Frequency analysis of digital computers operating in real time," Proc. IRE, vol. 42, pp. 457–466; February, 1954.
 R. Boxer and S. Thaler, "Extensions of Numerical Transform Theory," Rome Air Dev. Ctr. Tech. Rep. 56–115, November, 1956.

TABLE I Z Transforms and Z Forms

$rac{1}{S^k}$	$z$ transform $\overline{F}_k(z) = rac{N_k(z)}{D_k(z)}$	$z$ form $F_k(z)$
		$T_{\sigma} = T = T_{\sigma} \perp 1$
1 S	$\frac{z}{z-1}$	$\frac{Tz}{z-1} - \frac{T}{2} = \frac{T}{2} \frac{z+1}{z-1}$
$\frac{1}{S^2}$	$\frac{Tz}{(z-1)^2}$	$\frac{T^2z}{(z-1)^2} + \frac{T^2}{12} = \frac{T^2}{12} \frac{z^2 + 10z + 1}{(z-1)^2}$
$\frac{1}{S^3}$	$\frac{T^2}{2} \frac{z(z+1)}{(z-1)^3}$	$\frac{T^3}{2} \frac{z(z+1)}{(z-1)^3}$
$\frac{1}{S^4}$	$\frac{T^3}{6} \frac{z(z^2 + 4z + 1)}{(z - 1)^4}$	$\frac{T^4}{6} \frac{z(z^2 + 4z + 1)}{(z - 1)^4} - \frac{T^4}{720}$
$\frac{1}{S^b}$	$\frac{T^4}{24} \frac{z(z^3 + 11z^2 + 11z + 1)}{(z-1)^5}$	$\frac{T^{5}}{24} \frac{z(z^{3} + 11z^{2} + 11z + 1)}{(z - 1)^{5}}$
$\frac{1}{S^k}$	$\frac{Tz}{k-1} \frac{(k-1)N_{k-1}(z) - (z-1)N'_{k-1}(z)}{(z-1)^k}$	$T \overrightarrow{F}_k(z) + T^k A_k (-1)^{k/2+1}$ where $A_k$ is the Bernoulli Coefficient $^*$

Legend:

1) The  $N_k(z)$  terms include the constant multiplier.

2) The term  $N_k'(z)$  represents  $dN_k(z)/d(z)$ .

3) The general formula for  $F_k(z)$  holds for k > 1.

\* C. H. Richardson, "An Introduction to the Calculus of Finite Differences," D. Van Nostrand Co. Inc., New York, N. Y., pp. 45-46; 1954.

increased the amount of labor necessary to obtain a solution. Furthermore, the method had the inconvenience of the solution being in error at the origin. This was of small consequence, however, as this initial value was always known.

A group at Columbia University, under the direction of Millman, developed an operational method in which initial conditions are included in integrating and differentiating operators. The basic operators are those of Tustin, but the usefulness of the operators was considerably extended in that the origin problems were eliminated.

In this paper, a different approach to the problem of initial conditions is given. Although the procedure will be shown to be applicable to any of the methods indicated by Table II the basic derivations will be directed toward the z forms, because of their relatively greater accuracy. When applied to the operators of Tustin, the results obtained are similar to those derived at Columbia, except that additional terms are obtained which lead to greater accuracy in problems above the first order.

#### THEORY

The integrating operators shown in column 3 of Table I, can be derived by the procedure illustrated below for the second order case. 5,10 Given a function y(t), it is desired that  $i_2(t)$  be obtained where

$$i_2(t) = \int \int y(t)dt. \tag{6}$$

If (6) is to be approximated by a second-order difference equation, then

$$Ai_2(t+2T) + Bi_2(t+T) + Ci_2(t)$$
  
=  $Dy(t+2T) + Ey(t+T) + Fy(t)$ . (7)

In operational form

$$f(t+nT) = \epsilon^{pnT} f(t) \tag{8}$$

and

$$i_2(t) = \frac{1}{t^2} y(t).$$

Thus (7) can be expressed

$$\frac{A}{p^2} \epsilon^{2pT} y(t) + \frac{B}{p^2} \epsilon^{pT} y(t) + \frac{C}{p^2} y(t)$$

$$= D \epsilon^{2pT} y(t) + E \epsilon^{pT} y(t) + F y(t). \quad (9)$$

If the exponential operators are expanded in a Taylor Series, the coefficients A, B, C, D, E, and F can be determined by equating the maximum number of like powers of p on both sides of (9), consistent with the number of unknown coefficients. If this is done and the values of the coefficients are substituted into (7), the difference equation for second-order integration obtained is:

TABLE II
COMPARISON OF INTEGRATING OPERATORS

$1/S^k$	Method	Operator	Series Expansion of Operator
1 S	Tustin	$\frac{T}{2} \frac{z+1}{z-1}$	$\frac{1}{S} + \frac{ST^2}{12} - \frac{S^3T^4}{720} + \frac{S^5T^6}{30240} + \cdots$
	Madwed-Truxal	$\frac{T}{2} \frac{z+1}{z-1}$	$\frac{1}{S} + \frac{ST^2}{12} - \frac{S^3T^4}{720} + \frac{S^5T^6}{30240} + \cdots$
	Exact z Transform	$\frac{Tz}{z-1}$	$\frac{1}{S} + \frac{T}{2} + \frac{ST^2}{12} - \frac{S^3T^4}{720} + \frac{S^5T^6}{30240} + \cdots$
	z Form	$\frac{T}{2} \frac{z+1}{z-1}$	$\frac{1}{S} + \frac{ST^2}{12} - \frac{S^3T^4}{720} + \frac{S^5T^6}{30240} + \cdots$
$\frac{1}{S^2}$	Tustin	$\frac{T^2}{4} \frac{z^2 + 2z + 1}{(z - 1)^2}$	$\frac{1}{S^2} + \frac{T^2}{6} + \frac{S^2T^4}{240} - \frac{S^4T^6}{6048} + \cdots$
	Madwed-Truxal	$\frac{T^2}{6} \frac{z^2 + 4z + 1}{(z - 1)^2}$	$\frac{1}{S^2} + \frac{T^2}{12} + \frac{S^2 T^4}{240} - \frac{S^4 T^6}{6048} + \cdots$
	Exact z Transform	$\frac{T^2z}{(z-1)^2}$	$\frac{1}{S^2} - \frac{T^2}{12} + \frac{S^2 T^4}{240} - \frac{S^4 T^6}{6048} + \cdots$
	z Form	$\frac{T^2}{12} \frac{z^2 + 10z + 1}{(z - 1)^2}$	$\frac{1}{S^2} + \frac{S^2T^4}{240} - \frac{S^4T^6}{6048} + \cdots$
$\frac{1}{S^3}$	Tustin	$\frac{T^3}{8} \frac{z^3 + 3z^2 + 3z + 1}{(z - 1)^3}$	$\frac{1}{S^3} + \frac{T^2}{4} \frac{1}{S} + \frac{ST^4}{60} - \frac{S^3T^6}{60480} + \cdots$
	Madwed-Truxal	$\frac{T^3}{24} \frac{z^3 + 11z^2 + 11z + 1}{(z-1)^3}$	$\frac{1}{S^3} + \frac{T^2}{12} \frac{1}{S} + \frac{ST^4}{360} + \frac{13S^3T^6}{60480} + \cdots$
	Exact z Transform	$\frac{T^3}{2} \frac{z(z+1)}{(z-1)^3}$	$\frac{1}{S^3} \qquad -\frac{ST^4}{240} + \frac{S^3T^6}{3024} + \cdots$
	z Form	$\frac{T^3}{2} \frac{z(z+1)}{(z-1)^3}$	$\frac{1}{S^3} \qquad -\frac{ST^4}{240} + \frac{S^3T^8}{3024} + \cdots$
1 S <sup>4</sup>	Tustin	$\frac{T^4}{16} \frac{z^4 + 4z^3 + 6z^2 + 4z + 1}{(z-1)^4}$	$\frac{1}{S^4} + \frac{T^2}{3} \frac{1}{S^2} + \frac{13T^4}{360} + \frac{S^2T^8}{945} + \cdots$
	Madwed-Truxal	$\frac{T^4}{120} \frac{z^4 + 26z^3 + 66z^2 + 26z + 1}{(z-1)^4}$	$\frac{1}{S^4} + \frac{T^2}{12} \frac{1}{S^2} + \frac{T^4}{360} + \frac{S^2 T^6}{60480} + \cdots$
	Exact z Transform	$\frac{T^4}{6} \frac{z(z^2 + 4z + 1)}{(z - 1)^4}$	$\frac{1}{S^4} + \frac{T^4}{720} - \frac{S^2 T^6}{3024} + \cdots$
	z Form	$\frac{T^4}{6} \frac{z(z^2+4z+1)}{(z-1)^4} - \frac{T^4}{720}$	$\frac{1}{S^4}$ $-\frac{S^2T^6}{3024} + \cdots$

$$i_2(t+2T) - 2i_2(t+T) + i_2(t)$$

 $=\frac{T^2}{12}y(t+2T)+\frac{10T^2}{12}y(t+T)+\frac{T^2}{12}y(t). \quad (10)$ 

and if Laplace transformed, the result is

$$\frac{I_2(s)}{Y(s)} = \frac{T^2}{12} \frac{\epsilon^{2sT} + 10\epsilon^{sT} + 1}{\epsilon^{2sT} - 2\epsilon^{sT} + 1}$$
(11)

Eq. (10) has been derived neglecting initial conditions, or in z-transform notation

$$\frac{I_2(z)}{Y(z)} = \frac{T^2}{12} \frac{z^2 + 10z + 1}{(z - 1)^2}$$
 (12)

The remainder of the z forms shown in Table I can be derived in the same manner and represent difference equation approximations for integration that are optimum in the sense indicated.

If the initial conditions are not zero, the z transform of (10) yields terms in addition to those shown in (12). It can be shown<sup>11</sup> that the z transform of f(t+mT) is given by

$$\mathbb{Z}[f(t+mT)] = z^m \left[ F(z) - \sum_{n=0}^{m-1} f(nT) z^{-n} \right].$$
 (13)

Using (13), the z transform of (10) is

$$\frac{T^{2}}{12} \left[ z^{2}Y(z) - z^{2}y(0) - zy(T) \right] + \frac{10T^{2}}{12} \left[ zY(z) - zy(0) \right] + \frac{T^{2}}{12} Y(z) 
= z^{2}I_{2}(z) - z^{2}i_{2}(0) - zi_{2}(T) - 2 \left[ zI_{2}(z) - zi_{2}(0) \right] + I_{2}(z).$$
(14)

However, y(T),  $i_2(T)$ , and  $i_2(0)$  can be expressed:

$$y(T) = y(0) + Ty'(0) + \frac{T^2}{2!}y''(0) + \cdots$$

$$= \sum_{n=0}^{\infty} \frac{T^n}{n!} y^n(0)$$

$$i_2(T) = y^{-2}(0) + Ty^{-1}(0) + \frac{T^2}{2} y(0) + \cdots$$

$$= \sum_{n=0}^{\infty} \frac{T^n}{n!} y^{n-2}(0)$$

$$i_2(0) = y^{-2}(0).$$
(15)

Substituting (15) into (14), the result after algebraic manipulation is:

$$I_{2}(z) = \frac{T^{2}}{12} \frac{z^{2} + 10z + 1}{(z - 1)^{2}} Y(z) - \frac{T^{2}}{12} \frac{z(z + 10)}{(z - 1)^{2}} y(0)$$

$$- \sum_{n=0}^{\infty} \frac{T^{n+2}}{12n!} \frac{z}{(z - 1)^{2}} \left( \frac{n^{2} + 3n - 10}{n^{2} + 3n + 2} \right) y^{n}(0)$$

$$+ \sum_{q=1}^{2} \overline{F_{3-q}(z)} y^{-q}(0), \tag{16}$$

where  $\overline{F_k(z)}$  is the exact z transform for  $1/s^k$  given in Table I. Expanding (16) by performing the indicated summations yields:

$$I_{2}(z) = \frac{T^{2}}{12} \frac{z^{2} + 10z + 1}{(z - 1)^{2}} Y(z) - \frac{T^{2}}{12} \frac{z(z + 5)}{(z - 1)^{2}} y(0)$$

$$+ \frac{T^{3}}{12} \frac{z}{(z - 1)^{2}} y'(0) - \frac{T^{5}}{180} \frac{z}{(z - 1)^{2}} y'''(0) + \cdots$$

$$+ \frac{Tz}{(z - 1)^{2}} y^{-1}(0) + \frac{z}{z - 1} y^{-2}(0), \qquad (17)$$

<sup>11</sup> R. Boxer, "Analysis of sampled data systems and digital computers in the frequency domain," 1955 IRE CONVENTION RECORD, part 10, pp. 78-85.

where it should be noted that the second derivative term is absent. The result of a similar procedure for the firstorder integrating operator would be:

$$I_{1}(z) = \frac{T}{2} \frac{z+1}{z-1} Y(z) - \frac{Tz}{2(z-1)} y(0) + \frac{z}{z-1} y^{-1}(0).$$
 (18)

#### EXAMPLES

To illustrate the use of the z forms, including initial conditions, two problems will be carried out in some detail. The first is a constant coefficient problem, while the second is time varying.

### Example 1

A typical second-order differential equation with constant coefficients is

$$\frac{d^2y}{dt^2} + 3\frac{dy}{dt} + 2y = 0 \quad y(0) = +3; \quad y'(0) = -4. \quad (19)$$

The Laplace transform of (19) is

$$Y(s) + \frac{3}{s} Y(s) + \frac{2}{s^2} Y(s) = \frac{3}{s} + \frac{5}{s^2}.$$
 (20)

To obtain a difference equation approximation, (20) is z transformed, using (18) and the first three terms of (17) in the left side of the equation and the z transforms of Table I in the right side.

$$Y(z) + \frac{3T}{2} \frac{z+1}{z-1} Y(z) - \frac{9Tz}{2(z-1)} + \frac{T^2}{6} \frac{z^2 + 10z + 1}{(z-1)^2}$$

$$-\frac{T^2}{2}\frac{z(z+5)}{(z-1)^2} - \frac{2T^3z}{3(z-1)^2} = \frac{3z}{z-1} + \frac{5Tz}{(z-1)^2}.$$
 (21)

Solving for Y(z),

$$Y(z) = \frac{(18 + 27T + 3T^2)z^2 - (18 - 3T - 15T^2 - 4T^3)z}{(6 + 9T + T^2)z^2 - (12 - 10T^2)z + (6 - 9T + T^2)} \cdot (22)$$

If T is chosen as 0.1,

$$Y(z) = \frac{3.0z^2 - 2.539219z}{1.0z^2 - 1.722142z + 0.739508}.$$
 (23)

The solution for y(t) is obtained by carrying out the indicated synthetic division. The results are shown in Table III, together with the exact solution.

#### Example 2

A time-varying problem, suggested to the author by Millman, is

$$\frac{d^2}{dt^2} \left[ (t^2 - 1)y \right] - \frac{d}{dt} \left[ 2ty \right] - 6y = 0$$

$$y(0) = -0.5; \quad y'(0) = 0$$
(24)

TABLE III
SOLUTION OF CONSTANT COEFFICIENT PROBLEM

t	y(t)—Exact	y(t)—Calculated	t	y(t)—Exact	y(t)—Calculated
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9	3.000000 2.628405 2.307782 2.030448 1.789969 1.580941 1.398818 1.239767 1.100555 0.978439 0.871093	3.000000 2.627207 2.305900 2.028246 1.787697 1.578764 1.396840 1.238048 1.099120 0.977295 0.870233	0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9	$\begin{array}{c} -0.500000 \\ -0.485000 \\ -0.440000 \\ -0.365000 \\ -0.260000 \\ -0.125000 \\ +0.040000 \\ +0.235000 \\ +0.460000 \\ +0.715000 \\ +1.000000 \\ \end{array}$	$\begin{array}{c} -0.500000 \\ -0.485075 \\ -0.440299 \\ -0.365672 \\ -0.261194 \\ -0.126865 \\ +0.037321 \\ +0.231355 \\ +0.455240 \\ +0.708975 \\ +0.992555 \end{array}$

which has the analytic solution

$$y(t) = 0.5(3t^2 - 1)$$
  $0 \le t \le 1.0.$  (25)

Transforming (24) yields

$$\mathcal{E}[(t^2 - 1)y] - \frac{1}{s} \mathcal{E}[(2t)y] - \frac{6}{s^2} y = \frac{1}{2s}.$$
 (26)

Taking the z transform using (17) and (18):

$$c_{2}Y(z) - \frac{c_{1}T}{2} \frac{z+1}{z-1} Y(z) - \frac{T^{2}}{2} \frac{z^{2}+10z+1}{(z-1)^{2}} Y(z)$$

$$= \frac{z}{2(z-1)} + \frac{T^{2}}{4} \frac{z(z+5)}{(z-1)^{2}}$$
(27)

where

$$c_1 = 2t$$

$$c_2 = t^2 - 1 \tag{28}$$

Solving for Y(z)

rectly for a given set of initial conditions. One of the procedures is to obtain the first few values of the solution very accurately through the use of a Taylor series expansion and then to continue the solution using the difference equation. The operational procedure described in this paper is analogous to such a technique. The zform integrating operators lead to an accurate difference equation approximation to the differential equation with initial conditions equal to zero. The addition of the initial condition terms such as those in (17) and (18) adjust the numerator of the z-transform transfer function approximation in order that the solution may be started accurately. A first-order system requires only the initial condition in order to continue the solution. Thus, the first-order integrating operator given by (18) only need contain a term that is dependent upon the initial condition and, of course, initial integral values.

tions. Special care is required to start the solution cor-

TABLE IV

SOLUTION OF TIME-VARYING PROBLEM

Higher order problems, utilizing integrating relations such as (17), lead to higher order difference equations. A number of solution values equal to the order of the difference equation are required to start and continue

$$Y(z) = \frac{(12 + T^2)z^2 - (2 - 5T^2)z}{(4c_2 - 2c_1T - 2T^2)z^2 - (8c_2 + 20T^2)z + (4c_2 + 2c_1T - 2T^2)}$$
 (29)

With T = 0.1

$$Y(z) = \frac{2.01z^2 - 1.95z}{(4c_2 - 0.2c_1 - 0.02)z^2 - (8c_2 + 0.20)z + (4c_2 + 0.2c_1 - 0.02)}$$
(30)

Carrying out the indicated division, using (28) for the values of  $c_1$  and  $c_2$  at each step of the division process, yields the results shown in Table IV.

The procedure for solving a nonlinear problem is identical to that for time-varying problems, with the exception that the values obtained for the dependent variable are used to evaluate the denominator constants during the division process. The justification for treating the varying coefficients as constants was presented in a previous paper.<sup>4</sup>

#### DISCUSSION

In standard numerical analysis practice, differential equations are solved by difference equation approxima-

the solution. Thus, the integrating operators for  $1/s^k$  for k>1 contain an infinite number of terms that are functions of the higher derivatives of the solution. The greater the number of these terms used, the greater the accuracy of the initial values of the solution. This permits fuller utilization of the accuracy inherent in the characteristic difference equation.

This paper has illustrated the use of the z forms and initial condition terms as integrating approximations. One might desire to know whether the reciprocals of the z-form operators with suitable initial conditions could be used as differentiating operators. The same procedures for obtaining the integrating operators would yield for first- and second-order differentiation

$$D_{1}(z)$$

$$= \frac{2}{T} \frac{z-1}{z+1} Y(z) - \frac{2}{T} \frac{z}{z+1} y(0) + \frac{z}{z+1} y'(0)$$
(31)
$$D_{2}(z)$$

$$= \frac{12}{T_{2}} \frac{(z-1)^{2}}{z^{2}+10z+1} Y(z) - \frac{12}{T^{2}} \frac{z(z-1)}{z^{2}+10z+1} y(0)$$

$$- \frac{12}{T} \frac{z}{z^{2}+10z+1} y'(0) + \frac{z(z+5)}{z^{2}+10z+1} y''(0)$$

 $+\sum_{n=1}^{\infty} \frac{T^n}{n!} \frac{z}{z^2 + 10z + 1} \frac{n^2 + 3n - 10}{n^2 + 3n + 2} y^{n+2}(0). \quad (32)$ 

As differentiating operators, the use of (31) and (32) leads to difficulty in some problems. Terms such as  $(z^2+10z+1)$  in (32) do not contain the factor (z+1) as in (31). In certain applications this will cause the required difference equation to be of higher order than necessary, and introduces extraneous roots in the characteristic equation. These extraneous roots cause incorrect transient phonomena to appear. In fact, as the magnitude of the roots place them outside the unit circle in the z plane, the solution obtained is unstable. One should note, however, that the amount of labor required to solve a problem by derivative operators would be about the same as the amount of labor performed in using the integrating operators, even if the undesirable effects were not present. In practice, therefore, it is recommended that the integrating operators be used.

The method for introducing initial conditions shown here can be applied to the various available operators such as those of Table II in addition to the z-form operators. The required relations for integration of any order can be obtained by using the following equation:

$$I_{k}(z) = F_{k}(z)Y(z) + \sum_{m=0}^{\infty} \sum_{p=1}^{k} \sum_{n=p}^{k} \left[ b_{n} \frac{(pT - T)^{k+m}}{(k+m)!} - a_{n} \frac{(pT - T)^{m}}{m!} \right] \cdot \left[ y^{m}(0) \frac{z^{n-p+1}}{(z-1)^{k}} \right] + \sum_{q=1}^{k} \overline{F_{k-q+1}}(z) y^{-q}(0)$$
(33)

where

$$F_k(z) = \frac{a_k z^k + a_{k-1} z^{k-1} + \dots + a_0}{\bar{b}_k z^k + b_{k-1} z^{k-1} + \dots + b_0}$$
(34)

is any of the operators and

$$y^{0}(0) = y(0)$$

$$y^{n}(0) = \frac{d^{n}y}{dt^{n}}\Big|_{t=0}$$

$$y^{-q}(0) = \int \cdots \int_{-\infty}^{0} y(t)dt \qquad (35)$$

$$\overline{F_{k}}(z) = z \text{ transform for } 1/s^{k}.$$

When the initial condition terms are obtained for the Tustin operators, no difficulty is encountered in their use as differentiating operators. The first-order differentiating equation for Tustin's operator would be identical to (31), while that for second-order differentiation is

$$D_{2}(z) = \frac{4}{T^{2}} \frac{(z-1)^{2}}{(z+1)^{2}} Y(z) - \frac{4}{T^{2}} \frac{z(z+1)}{(z+1)^{2}} y(0)$$

$$- \frac{4z}{T(z+1)^{2}} y'(0) + \frac{z}{z+1} y''(0)$$

$$+ \sum_{n=1}^{\infty} \frac{T^{n}}{n!} \frac{z}{(z+1)^{2}} \left( \frac{n^{2}+3n+2}{n^{2}+3n+2} \right) y^{n+2}(0). \quad (36)$$

It is to be emphasized that a method for extending the Tustin operators for initial conditions was first accomplished by the Millman group at Columbia. They have also made extensive use of the flexibility, due to the ability to use the operators in either the integrating or differentiating sense. The procedure of this paper, however, when applied to the Tustin forms yields additional corrective terms, such as represented by the series

$$\sum_{n=1}^{\infty} \frac{T^n}{n!} \frac{z}{(z+1)^2} \left( \frac{n^2 + 3n - 2}{n^2 + 3n + 2} \right) y^{n+2}(0) \tag{37}$$

in (36).

A final comment may be appropriate. The method for obtaining a numerical solution is equally valid from the time and frequency domain points of view. The differential equations used in the illustrative examples could have been integrated directly, yielding in operational form

$$y(t) + \frac{3}{p} y(t) + \frac{2}{p^2} y(t) = 3 + \frac{5}{p}$$
 (38)

for the constant coefficient case and

$$(t^2 - 1)y(t) - \frac{1}{p}(2t)y(t) - \frac{6}{p^2}y(t) = 0.5$$
 (39)

for the time-varying problem. Upon z transforming these equations, substituting the z-form operators for the indicated integration operators, the solution proceeds as before.

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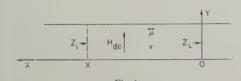
Thanks are also due J. Millman of Columbia University for many interesting and stimulating discussions relating to the numerical transform field.

# Correspondence.

# Transverse Impedance Transformation for Ferromagnetic Media\*

This letter describes a transverse impedance transformation for ferromagnetic media magnetized in a transverse direction. It is valid for TEmp modes when the magnetization is in the direction of the E field.

Fig. 1 indicates the basic geometry.



The propagation is in the +Z direction and  $e^{j\omega_t-\gamma_z}$  variation is assumed for all three field components  $E_y$ ,  $H_x$ , and  $H_z$ . It is well known that the solutions of the tensor wave

$$\nabla \times \nabla \times \overrightarrow{H} = \overset{\longleftrightarrow}{\omega^2 \epsilon \mu \cdot H} \text{ are }$$

$$E_{\nu} = A \sin K_{mY} + B \cos K_{mY}$$

$$E_y = A \sin \Lambda_m \chi + B \cos \Lambda_m \chi$$

$$H_z = \frac{j}{\omega \mu_{\text{eff}}} \left[ \left( K_m A + j \frac{K}{\mu} \gamma B \right) \cos K_m \chi + \left( -K_m B + j \frac{K}{\mu} \gamma A \right) \sin K_m \chi \right]$$

for the transverse components, where

$$\begin{split} & \underset{\mu_{xyz}}{\leftrightarrow} = \begin{bmatrix} \mu & 0 & jK \\ 0 & \mu_0 & 0 \\ -jK & 0 & \mu \end{bmatrix} \\ & K_{m^2} = \omega^2 \mu_{\rm eff} \epsilon + \gamma^2 \quad {\rm and} \quad \mu_{\rm eff} = \frac{\mu^2 - K^2}{\mu}. \end{split}$$

Since tangential E and H are matched at all transverse boundaries a transverse impedance  $Z_t = E_y/H_z$  is defined (1).

At x = 0

$$Z_{t}(0) = \frac{-j\omega\mu_{\rm eff}B}{K_{m}A + j\frac{K}{\mu}\gamma B} = Z_{L}.$$

Solving for B and substituting in the expression for  $Z_t$  gives after simplification (2).

$$\frac{-\omega \mu_{\rm eff}}{K_m} \sqrt{\frac{\frac{\mu_{\rm eff}}{\epsilon}}{1 + \left(\frac{\lambda_{0m}\gamma}{2\pi}\right)^2}}$$

$$= \sqrt{\frac{\frac{\mu_{\rm eff}}{\epsilon}}{1 - \left(\frac{\lambda_{0m}}{\lambda_g}\right)_{\gamma=i\beta}^2}} \equiv Z_{0m}.$$

Therefore, it is readily seen (3), especially from the second form, that  $Z_t$  reduces to the

$$Z_{I} = \frac{-j\omega\mu_{\rm eff}(A\,\sin\,K_{m}\chi + B\,\cos\,K_{m}\chi)}{\left(K_{m}A + j\,\frac{K}{\mu}\,\gamma B\right)\cos\,K_{m}\chi + \left(j\,\frac{K}{\mu}\,\gamma A - K_{m}B\right)\sin\,K_{m}\chi} \,. \tag{1}$$

$$Z_{t} = \frac{\frac{\omega \mu_{\text{eff}}}{K_{m}} \left[ \frac{K_{m} Z_{L}}{\omega \mu_{\text{eff}}} \cos K_{m} \chi - j \left( \frac{K}{\mu} \gamma \frac{Z_{L}}{\omega \mu_{\text{eff}}} + 1 \right) \sin K_{m} \chi \right]}{\cos K_{m} \chi + j \left[ \left( \frac{K}{\mu} \gamma \right)^{2} \frac{Z_{L}}{K_{m} \omega \mu_{\text{eff}}} + \frac{K}{\mu} \frac{\gamma}{K_{m}} - \frac{K_{m} Z_{L}}{\omega \mu_{\text{eff}}} \right] \sin K_{m} \chi}$$
(2)

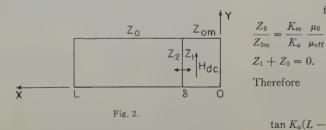
$$\frac{Z_t}{Z_{0m}} = \frac{Z_L}{Z_{0m}} \cos K_m \chi + j \left(1 - \frac{K}{\mu} \frac{\gamma}{K_m} \frac{Z_L}{Z_{0m}}\right) \sin K_m \chi}{\cos K_m \chi + j \left[\frac{Z_L}{Z_{0m}} \left\{1 - \left(\frac{K}{\mu} \frac{\gamma}{K_m}\right)^2\right\} + \frac{K}{\mu} \frac{\gamma}{K_m}\right] \sin K_m \chi}$$

$$= \frac{\left(\frac{Z_L}{Z_{0m}}\cot K_m \chi + j}{\cot K_m \chi + j} - \left(\frac{j\frac{K}{\mu}\frac{\gamma}{K_m}\frac{Z_L}{Z_{0m}}}{\cot K_m \chi + j\frac{Z_L}{Z_{0m}}}\right) - \left(\frac{j\frac{K}{\mu}\frac{\gamma}{K_m}\frac{Z_L}{Z_{0m}}}{\cot K_m \chi + j\frac{Z_L}{Z_{0m}}}\right)}{\cot K_m \chi + j\frac{Z_L}{Z_{0m}}} - \frac{j\frac{K}{\mu}\frac{\gamma}{K_m}\left[1 - \left(\frac{K}{\mu}\frac{\gamma}{K_m}\right)\frac{Z_L}{Z_{0m}}\right]}{\cot K_m \chi + j\frac{Z_L}{Z_{0m}}}.$$
(3)

$$\frac{Z_t}{Z_{0m}} = \frac{\frac{Z_L}{Z_{0m}} \left( \cot K_m \chi + \frac{K}{\mu} \frac{\beta}{K_m} \right) + \left( \cot K_m \chi - \frac{K}{\mu} \frac{\beta}{K_m} \right) + j \frac{Z_L}{Z_{0m}} \left[ 1 + \left( \frac{K}{\mu} \frac{\beta}{K_m} \right)^2 \right]} \cdot$$
(4)

familiar impedance transformation when the ferromagnetic is demagnetized and K=0,  $\mu = \mu_0$ . If  $\gamma = j\beta$ , for the lossless case, (4).

Any geometry (such as Fig. 2) where transverse boundary conditions must be matched may now be solved using standard transverse resonance techniques.



Waveguide equations hold in each region:  $K_a^2 = \omega^2 \mu_0 \epsilon_0 + \gamma^2$  (in the air-filled section)  $K_{m^2} = \omega^2 \mu_{\rm eff} \epsilon + \gamma^2$  (in the ferromagnetic section)  $\mu_{\rm eff} = \frac{\mu^2 - K^2}{\mu}.$ 

The sum of transverse impedances must equal 0 at any x, but pick  $x = \delta$  for convenience.

$$\frac{Z_2}{Z_0} = j \tan K_a(L - \delta)$$

from normal Z transformation

$$(Z_L = 0)$$

$$\frac{Z_1}{Z_{0m}} = \frac{j}{j \frac{K}{\mu} \frac{\gamma}{K_m} + \cot K_m \delta}$$

from Z transformation just derived for ferrite section  $(Z_L = 0)$ 

$$\frac{Z_0}{Z_{0m}} = \frac{K_m}{K_a} \frac{\mu_0}{\mu_{\text{eff}}}$$
$$Z_1 + Z_2 = 0.$$

$$\tan K_a(L-\delta) = \frac{-K_a \frac{\mu_{\text{eff}}}{\mu_0}}{j \frac{K}{\mu} \gamma + K_m \cot K_m \delta}$$

as is well known from Button and Lax's work.1

> Frederic R. Morgenthaler AF Cambridge Res. Ctr. Bedford, Mass.

<sup>1</sup> K. J. Button and B. Lax, "Theory of ferrites in rectangular waveguide," IRE TRANS., vol. AP-4, pp. 531-537; July, 1956.

<sup>\*</sup> Received by the IRE, April 29, 1957.

# Doppler Shift of the Received Frequency from the Standard Station Reflected by the Ionosphere\*

While comparing the frequency from the standard station JJY of Japan with that of the Stark modulation atomic clock1 here, we experienced that the received frequency shifted, which could be attributed to the movement of the ionosphere.1,2 Then we expected it should be possible to investigate the ionosphere by measuring Doppler shift.

As a preliminary experiment for this investigation, we made a continuous recording of the beat frequency between the received frequency of a standard wave (4 mc) from JJY and that of the quartz chronometer (100 kc) in our laboratory. The stability of the quartz chronometer was better than 2×10<sup>-8</sup> per day, and was considered sufficient for our purpose.

The block diagram of the apparatus is shown in Fig. 1.

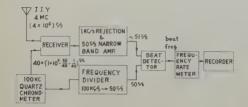


Fig. 1-Block diagram of the apparatus.

In Fig. 2 is shown the schematic diagram of the beat detector, which was used to improve signal-to-noise ratio and consisted of a phase sensitive detector modified for our purpose. The frequency rate meter was of a common type.3,4 The whole apparatus was able to be operated continuously without changing recording paper for about 12 days.

As a typical example, Fig. 3 shows the observations from November 10-13, 1956. Our laboratory in Kyoto (E 139°29.3', N 35°42.4') is about 400 km away from the standard frequency station JJY in Tokyo (E 135°47.5', N 35°01.7'). During the day (0700-1600), a radio wave of 4 mc is reflected by the E layer and the received frequency was very stable as shown by the flat curve in Fig. 3, though the field intensity was rather weak. Therefore, the virtual height of the E layer at which the radio wave was reflected was concluded to be almost constant. This is consistent with the constancy of the virtual height of the maximum electron density of the E layer, which is widely known. At night, the electric field intensity was strong but was accompanied

\*Received by the IRE, May 13, 1957.

1 I. Takahashi, T. Ogawa, M. Yamano, A. Hirai, and M. Takeyama, "Stark modulation atomic clock," ev. Sci. Instr., vol. 27, pp. 739–745; September, 1956.

2 See, e.g., J. M. Steele, "The standard frequency monitor at the National Physical Laboratory," Proc. IEE, vol. 102, part B, pp. 155–165; March, 1955.

2 W. C. Elmore and M. Sands, "Electronic Experimental Techniques," McGraw-Hill Book Co., Inc., New York, N. Y., p. 202; 1949.

4 R. M. Kloepper and F. E. Hoecker, "A double-channel, direct reading, low frequency counting rate meter and counting rate comparator," Rev. Sci. Instr., vol. 20, pp. 17–22; January, 1949.

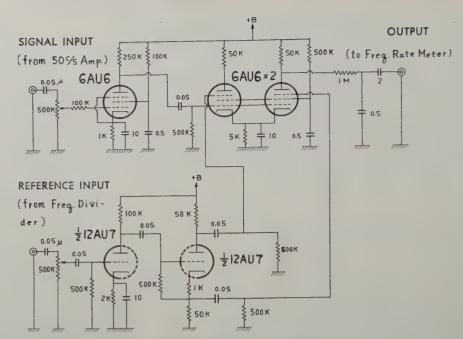


Fig. 2-Schematic diagram of the beat detector.

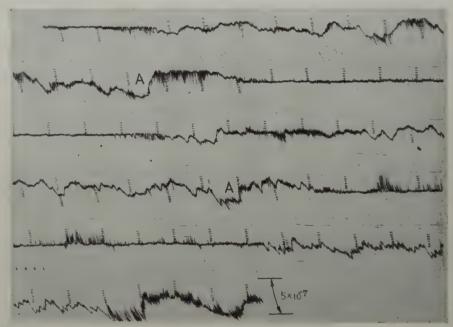


Fig. 3—A typical example of observations: continuous recording of the beat between the received frequency of 4 mc from JJY and that of the quartz chronometer (100 kc). Deflection downwards corresponds to the increase of the received frequency. Time (JST) is represented in figures, in such a way that the first two denote the date of November, 1956; the second, the hour of the day; and the last, the minutes, e.g., 101500 stands for 1500, November 10, 1956.

by deep fadings, and the received frequency fluctuated in the magnitude of the order of 10<sup>-7</sup> as seen in Fig. 3. In this case, the radio wave was reflected by the Flayer. The peak denoted by point A in Fig. 3 appeared just before 0500 every day, so from this time, the E layer seemed to become rapidly appreciable and the radio wave became reflected by the E layer again. This method could be developed so that more detailed information about the ionosphere might be obtained. for example, dynamic behavior and small fluctuation in short time. Since an inverted-L-type antenna 20 meters long was used, the

radio waves coming by different paths were received. For further precise observations, a directional receiving antenna would be

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I. TAKAHASHI, T. OGAWA. M. Yamano, A. Hirai, AND M. TAKIUCHI Department of Physics and Abuyama Seismological Observatory Kyoto University Kyoto, Japan

# On the Statistics of Individual Variations in Productivity in Research Laboratories\*

Unfortunately, Mr. Shockley's observations in the above paper, include no mention of creative productivity resulting from incentives other than an annual salary.

That approximately half of the annual patent output goes to independent inventors, with no salary consideration whatsoever, is indicated by patent statistics. Here, creativity is defined by the patent statutes, as contrasted with published material of other types—creative, analytical, or merely reportorial—which form so large a part of Shockley's case histories, wherein the annual salary appears to constitute the chief incentive.

It is generally recognized that special incentives, such as financial rewards over and above a salary, produce greater invention productivity than mere elevation of professional stature as measured by paper publication rate or salary alone. For this reason, unsalaried independent inventors and salaried inventors with extra incentives produce much more creative output than the "salary-only" researchers.

However, the project team concept, so widely practiced in the larger industrial laboratories, is not very amenable to the extra compensation plan, although some of these laboratories do use it to some not very remunerative degree. But with the independent inventor, financial incentive is almost always the prime incentive. But, his creative activities are not confined by company policies into narrow channels.

Since promotion of scientific and engineering creativity is now so much in the forefront of our public's concern, especially in view of Russia's strenuous efforts to achieve this creativity, it appears that the key to the preservation of the well-springs of our very way of life itself, is the restoration of the stimuli which have worked so well in the past. These fruitful incentives have all but disappeared in the workings of our large industrial laboratories, which are so frantically outbidding one another for our young scientists and engineers.

It has been proven many times that creativity lies in the individual mind and not in the project team. The latter, with many specialized-training members, can effectively and quickly whip the raw creation into commercially usable shape, but it can never invent anything; nor has it any real incentive to do so. This applies almost as well to the individual members of these teams simply because the catalytic stimuli are lacking.

"Our species is the only creative species, and it has only one creative instrument, the individual mind and spirit of man. There are no good collaborations, whether in music, in art, in poetry, in mathematics, in philosophy. Once the miracle of creation has taken place, the group can build and extend it,

but the group never invents anything. The preciousness lies in the lonely mind of man."2

When those who set policies in our large industrial enterprises realize these fundamental facts, and act on them wisely, the tradition of Yankee ingenuity will again come into full flower, and we need never fear Russia or any other nation. But if we continue to allow our former system of adequate incentives for invention creativity to retrogress, as it has been during the past 30 years, we will be as insecure industrially as we would be biologically, if we reduced, to a tenuous thread, the stimuli and rewards for reproduction of our species. We are now well along that road, for the patent output has already dropped to almost half of that of a quarter century ago.

As a constructive and informative suggestion, may I add that for several years now our Congress has been holding hearings and receiving reports on the workings of our Patent System, and in my opinion, a study of these workings and the various bills for improvement of this system would be very worthwhile.

Benjamin F. Miessner Miessner Inventions, Inc. Morristown, N. J. (Also Pres., Patent Equity Assn.)

<sup>2</sup> Quoted from J. Steinbeck, "East of Eden," by Reader's Digest, p. 20; August, 1957. See also, C. Fadiman (ed.), "American Treasury," Harper and Brothers, New York, N.Y.

### Author's Comment<sup>3</sup>

Mr. Miessner's thoughtful comments evidently represent an experienced and sincere evaluation of the relative importance of various incentives in provoking invention. His professional experience is quite different from mine and this may explain why his views are not ones I can wholly accept.

Actually, in his discussion of incentives, he starts a new subject and one which I did not attempt to treat in my paper. I think it would be much more difficult to deduce quantitative conclusions about incentives than about productivity.

I disagree with Miessner's main conclusion. I am not an advocate of a system which gives specific monetary rewards to a member of an industrial laboratory for the filing of a patent application or the issuance of a patent. I think the disadvantages of such a system far outweigh the advantages. The chief disadvantages, in order of increasing importance, are:

1) Individuals are motivated to get inventions processed regardless of worth. This clutters up the company's patent department, leads to patent emphasis for the most aggressive rather than the most brilliant inventor, and compounds confusion in the patent literature.

2) The emphasis of the work of the development engineer is shifted towards claiming originality rather than creating.

3) Cooperation between individuals and the free flow of ideas is inhibited.

An inventor in a conference will hold back ideas which might lead to inventions until he has had an opportunity to work them up to the point where his rights are preserved. More ill will results from circumstances surrounding the determination of who invented what when the winners get a specific financial reward. While at Bell Telephone Laboratories, where I was one of the most active inventors over a period of several years, I was often glad that no patent incentive system existed. I am sure it would have made my relationship with the members of my group much more difficult if I had been getting extra money for making inventions stimulated by their activities.

Furthermore, there are grave difficulties in trying to assess the work of an application or patent. To give a fixed reward for each application is unjust. To give a reward determined by executive judgment is much better. In fact, this is essentially what is done now and by using executive judgment, patents, publications, and other factors are weighed in a subjective way<sup>4</sup> and used to determine salary.

I disagree with Miessner's paragraph on the project team. I believe that the environment of a project team can be highly stimulating to the individual. In my own case, I recall that the basic thinking preceding the invention of the junction transistor was stimulated by an active experimentation program on semiconductor surfaces.

Fortunately, we live in a time and country where many patterns of activity are possible. Here, Miessner and I agree in personally seeking more challenge and stimulation outside of a large organization. Depending on his tastes, the outstanding young engineer can find or make his opportunity today either as a member of a very large and secure team with less personal incentives, or as an independent inventor or consultant with maximum incentives, or in the middle ground of smaller enterprises like my own.

WILLIAM SHOCKLEY
Shockley Semiconductor Lab.
of Beckman Instr. Inc.
Mountain View, Calif.

#### Letter from Mr. Miessner<sup>5</sup>

I agree with Mr. Shockley's three objections to specific monetary awards for creative work in industrial laboratories, but individual awards are made nevertheless in inventive credit for patent applications, authorship of papers, or promotion in rank, not to mention monetary awards in the form of salary increases. Therefore, these objections, as well as his others, are applicable in either case, to project teams in the large laboratories.

<sup>\*</sup> Received by the IRE, March 18, 1957, ¹ W. Shockley, Proc. IRE, vol. 45, pp. 279–290; March, 1957.

Received by the IRE, April 25, 1957.

<sup>4</sup> Shockley, op. cit., p. 287.

<sup>\*</sup> Received by the IRE, June 14, 1957,

As to the project team environment, I can think of no better argument against it than H. L. Mencken's "The Cosmic Secretariat," reprinted in his more recent "Crestomothy." Additionally I may mention that, when an outstanding ability develops in such teams, that individual, more often than not, leaves it for the more rewarding climate of individual effort, as evidenced by Mr. Shockley's own experience. Mr. Mueller<sup>6</sup> has also strongly supported my own convictions anent project team creativity.

I still maintain that the most favorable climate for most productive creativity does not exist in the project teams of our large laboratories and that some satisfactory solution must be found if we, as a nation, are to match the reported incentives now prevalent in our chief competitor, Russia.

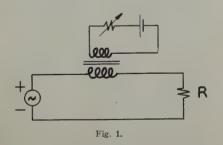
B. F. MIESSNER

<sup>6</sup> R. E. Mueller, "A note on the limits of brainstorming," Proc. IRE, vol. 45, p. 874; June, 1957.

# A General Circuit Theorem on Rectification\*

The prospect of achieving rectification using nonlinear capacitors and nonlinear inductors with dc bias would appear to be promising from the point of view of avoiding losses inherent in the nonlinear resistors in present circuits. No nonlinear resistors (diodes, switches, etc.) are perfect, and hence energy is always lost in the rectification process.

The circuit of Fig. 1 illustrates an elementary application of this idea. A sinusoidal voltage source feeds the linear resistance *R*, representing the load, through a



nonlinear inductance biased to the knee of the saturation curve by a dc current in a second winding. However, analysis of this circuit gives zero average current through the load, regardless of the shape of the magnetization curve or the bias point.

Unless one is easily discouraged, he may not be convinced that this one example disproves the possibility of obtaining rectification by some other combination of nonlinear reactive elements. One must also consider the possibility of using more than one source in the circuit. Speculation on these

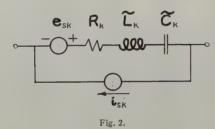
\*Received by the IRE, May 6, 1957; revised manuscript received, June 10, 1957.

possibilities may be ended once and for all by the following theorem.

Theorem: It is impossible to obtain a rectified dc power output from an ac source or sources unless nonlinear resistance is present in the circuit.

To prove this theorem, consider a general network containing any number of sinusoidal voltage and current sources, nonlinear capacitors, nonlinear inductors, and linear resistors. The inductors may be permanently magnetized and may be coupled to other parts of the circuit. The reactive elements may have hysteresis loss, but other losses, such as eddy current loss, must be represented by equivalent linear resistance.

The most general branch of this network is as shown in Fig. 2, where only the resistance need be linear.  $\widetilde{L}_k$  includes all series elements whose voltage drop depends on a rate of change of flux linkages, and  $\widetilde{C}_k$  includes all elements whose voltage drop depends on the amount of stored charge.



All branches containing series capacitance may be eliminated from further consideration, since any dc currents must flow around closed loops without capacitance. Thus, the problem reduces to a consideration of the subgraph obtained by eliminating these branches.

Next, Kirchhoff loop equations for the average voltages across the elements are written for this subgraph. The average voltage across an inductance is shown to be zero as follows:

$$\begin{split} \frac{1}{T} \int_0^T N \frac{d\phi}{dt} dt &= \frac{N}{T} \int_0^T d\phi \\ &= \frac{N}{T} \left[ \phi(T) - \phi(0) \right] = 0, \end{split}$$

where T is the period if all sources have the same frequency.  $\phi$  is the total equivalent flux, including mutual flux. If the frequencies are different, T may be some common period. If the frequencies are arbitrary irrational numbers, T may be made to approach infinity; that is, the average must be taken over a long time. Note that the above is still true even if hysteresis loss is present.

The average voltages or currents of the ac sources are, of course, zero. Thus, the equations reduce to sums over the dc voltage drops across the resistors alone. Since the resistors are all linear, the dc voltage drop for any resistor is given by the product of the resistance and the average value of the current.

The problem is, therefore, equivalent to that of a resistive network in which all sources are zero. The voltage across any resistor is zero. Thus, the average voltage across any resistor in the general nonlinear network with linear resistors is also zero.

Finally, a few words may be said concerning the general nonlinear network, wherein nonlinear resistors are included. Here, the currents from the capacitance branches again have an average value of zero. However, the voltage drop across the nonlinear resistors due to these currents is not necessarily zero. One may, therefore, utilize these currents to decrease the average power loss in the nonlinear resistors for a given average voltage and average current. By the same reasoning as in the case with linear resistors, one sees that the amount of rectified power output depends directly on the average voltage and average current in the nonlinear resistors. For example, for the case of a circuit with one linear and one nonlinear resistor, the product of the average voltage drop and average current for the nonlinear resistor is the negative of the dc power for the linear resistor.

Thus, in the general case one may utilize nonlinear (or linear) reactive elements to optimize the efficiency of rectification for a given dc power output when using imperfect nonlinear resistors.

James W. Gewartowski Electronic Labs. Stanford University Stanford, Calif.

# A Calibration Procedure for Microwave Radiometers\*

One of the persistent problems of microwave radiometry is the calibration of the radiometer in terms of the absolute temperature of a thermal source. The usual method is to substitute a noise source, either a hot load or a gas tube, for the antenna, and to calibrate the radiometer with this source. A difficulty with this procedure is the fact that the entire antenna system, with all its losses and multiple lobes, is interposed between the source to be measured and the point at which the calibrating signal is introduced. Determination of the unknown temperature thus requires a knowledge of the complete antenna pattern, including side and back lobes, as well as the absolute gain in the forward direction. This information is not easy to obtain. In addition, matching problems are introduced by the interchange of noise source and antenna.

A calibration procedure developed in this laboratory eliminates some of these difficulties, and also corrects for atmospheric absorption. Consider the idealized antenna shown in Fig. 1. A is the fractional energy radiated into (or received from) the for-

<sup>\*</sup> Received by the IRE, June 3, 1957.

1 R. N. Whitehurst, J. Copeland, and F. H. Mitchell, "Solar radiation and atmospheric attenuation at 6-millimeter wavelength." J. Appl. Phys., vol. 28, pp. 295-298; March, 1957.

ward lobes; B, the fractional energy radiated into the side lobes; and C, the fractional energy radiated into the back lobes.  $\Omega$  is the effective solid angle subtended by the for-

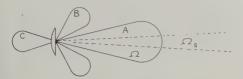


Fig. 1-Idealized antenna patter 1.

ward lobes as weighted by the antenna gain, and  $\Omega_s$  is the weighted solid angle subtended by the source to be measured.

Let the antenna be directed toward a point in the sky to the west of the source to be measured and be fixed in position. Assume that thermal radiation is received from the atmosphere in the forward lobes and from the ground and surroundings in the side and back lobes. If the atmosphere is assumed isothermal at ambient temperature,  $T_0$ , and the average temperatures "seen" by the side and back lobes are  $T_B$  and  $T_C$ , respectively, the antenna temperature is

$$T_1 = AT_0(1 - e^{-TVA \sec \theta}) + BT_B + CT_C$$

where TVA is the total attenuation in a vertical path through the atmosphere, and  $\theta$ is the angle between the direction of observation and the zenith.

When the source in its westward motion moves into the center of the beam, the antenna temperature becomes

$$T_2 = T_1 + \frac{\Omega_s}{\Omega} A T_s e^{-TVA \sec \theta}$$

where  $T_s$  is the weighted mean source tem-

Finally, let a piece of microwave absorber at ambient temperature be placed so that it intercepts only the forward lobes. The antenna temperature becomes

$$T_3 = AT_0 + BT_B + CT_C.$$

Suppose that the radiometer output scale deflections corresponding to temperatures  $T_1$ ,  $T_2$ , and  $T_3$  are  $d_1$ ,  $d_2$ , and  $d_3$ , respectively. Then

$$d_2 - d_1 = k(T_2 - T_1) = k \frac{\Omega_s}{\Omega} A T_s e^{-TVA \sec \theta}$$

$$d_3 - d_1 = k(T_3 - T_1) = KAT_0e^{-TVA \sec \theta}$$

where k is the radiometer sensitivity. Solution of these equations yields, for the weighted mean source temperature,

$$T_s = \frac{\Omega}{\Omega_s} \, \frac{d_2 - d_1}{d_3 - d_1} \, T_0.$$

Therefore, the three deflections plus knowledge of the shape of only the forward lobes of the antenna pattern are sufficient to determine the average source temperature in terms of ambient temperature. The ratio  $\Omega/\Omega_s$  is easily determined graphically.<sup>1</sup>

The primary advantage of this procedure is that the antenna losses and the radiation in the side and back lobes are included as part of the radiometer. They raise the noise figure but do not affect the calibration.

The assumption that the atmosphere is isothermal at To needs examination. Actually, of course, it is not. However, except at large zenith angles, it may be assumed isothermal at some temperature, which must be near ambient since most of the contribution is from the lower layers of the atmosphere. Analysis shows that if the attenuation is reasonably small a large error in the assumed atmospheric temperature would be required to cause a significant error in the source temperature measurement. A verification of the validity of this assumption has been made experimentally. If it were significantly in error, the measured temperatures would depend on zenith angle. No such dependence has been found, either at 6 or 7.5 mm wavelength.

> R. N. Whitehurst F. H. MITCHELL University of Alabama University, Ala. J. COPELAND North American Aviation Downey, Calif. Formerly University of Alabama University, Ala.

# The Effective Electrical Constants of Soil at Low Frequencies\*

The anomalous electrical properties of soils at low radio frequencies can have a profound influence on the propagation of the ground wave.1 This factor is generally overlooked. It may seem rather unusual that relative dielectric constants of the order of 103 prevail in many soils at frequencies of the order of 15 kc. In fact, in this frequency range Smith-Rose<sup>2</sup> has found that the apparent dielectric constant varies almost inversely with frequency. The apparent conductivity also varies with frequency. Usually the conductivity increases with increasing frequency becoming more or less constant at 1 mc.

It is the purpose of this note to present a simple phenomenological theory for the measured behavior of alternating current conduction in soils and rocks and low radio frequencies. It is supposed that the medium is a heterogeneous one consisting of small. highly-conducting particles each covered with a thin gaseous film. Such films occur in many instances on conduction of current from an electrolytic solution to a metallic electrode. It is quite possible that a similar condition exists in soils at rocks in situ where the pores are filled or partially filled with an electrolytic fluid. At higher radio frequencies the reactance of thin film sur-

\* Received by the IRE, July 25, 1957.

J. R. Wait and L. L. Campbell, "Effect of a large dielectric constant on ground wave propagation," Can. J. Phys., vol. 31, pp. 456–457; April, 1953.

R. L. Smith-Rose, "Measured electrical properties of soils for alternating current," J. IEE, vol. 75, pp. 231–237; March, 1934.

rounding the particle is negligible and the effective conductivity and dielectric constant would not be expected to be frequency dependent. At the lower frequencies, however, the reactance of the encasing film becomes significant and imparts an appreciable phase shift between the macroscopic current density and the applied electric field. In the analysis that follows, the particles are assumed to be spherical in shape, each with a concentric dielectric film.

A single spherical particle of conductivity  $\sigma_p$ , radius a, has an insulating film of thickness  $t_m$  and dielectric constant  $\epsilon_m$ . The suspending medium has a conductivity  $\sigma$ . A conventional spherical coordinate system  $(r, \theta, \phi)$  is chosen with the origin at the center of a single particle. The applied electric field  $E_0e^{iwt}$  is in the polar  $(\theta=0)$ direction. The resulting potentials  $\phi_n$  and  $\phi$ inside and outside the particle, respectively, are solutions of Laplace's equation since the significant dimensions in the problem are small compared to the wavelength. The boundary conditions at the film are that the normal current density is continuous and that the potentials are discontinuous by an amount equal to the voltage across the film. These two conditions lead to the following equations:

$$\sigma \frac{\partial \phi}{\partial r} \Big|_{r=a+t_m} = \sigma_p \frac{\partial \phi_p}{\partial r} \Big|_{r=a} \tag{1}$$

$$\phi - \frac{t_m \sigma}{i \epsilon_{n,\omega}} \frac{\partial \phi}{\partial r} \bigg|_{r=a+t_m} = \phi_p \bigg|_{r=a}$$
 (2)

where it is assumed that  $t_m \ll a$ . The exterior potential function is then found to be

$$\phi = -E_0 r \cos \theta + \frac{E_0 a^3}{r^2} \left[ \frac{1-\delta}{1+2\delta} \right] \cos \theta \quad (3)$$

where

$$\delta = \frac{\sigma}{\sigma_v} + \frac{t_m \sigma}{i \epsilon_m \omega a} \cdot$$

Now if there are N such particles per unit volume arranged in a regular lattice, the dipole moment A per unit volume per unit applied field is

$$A = 3v \frac{1 - \delta}{1 + 2\delta} \tag{4}$$

where  $v = 4\pi a^3 N/3$  is the volume of particles per unit volume. The Clausius-Mosotti relation of dielectric theory3 can now be employed to obtain an expression for the effective conductivity  $\sigma_e$  and dielectric constant  $\epsilon_{\theta}$  of the array of spherical particles, so that

$$\sigma_e + i\omega\epsilon_e = \sigma \left(1 + \frac{A}{1 - A/3}\right).$$
 (5)

To illustrate this result it is assumed that the volume loading of the particles is small (i.e.,  $v \le 1$ ) and that the conductivity of the particles is large (i.e.,  $\sigma_p \gg \sigma$ ). It then follows

$$\frac{\sigma_e + i\omega\epsilon_e}{\sigma} \cong 1 + 3v\left(\frac{1-\delta}{1+2\delta}\right). \tag{6}$$

<sup>3</sup> H. Frohlich, "Theory of Dielectrics," Oxford University Press, London, England, p. 169; 1949.

Consequently,

$$\frac{\sigma_s}{\sigma} \cong 1 + 3v \frac{1 - 2X^2}{1 + 4X^2} \tag{7}$$

and

$$\frac{\epsilon_e \omega}{\sigma} \cong \frac{9vX}{1 + 4X^2} \tag{8}$$

where

$$X = \frac{t_m \sigma}{\omega \epsilon_m a}$$

If  $X\gg 1$ , the particle behaves essentially as an insulator and

$$\frac{\sigma_e}{\sigma} \simeq 1 - 3v/2 \text{ and } \epsilon_e \omega/\sigma \simeq 9v/4X.$$
 (9)

If the admittance of the film is very large such that  $X \ll 1$ ,

$$\frac{\sigma_e}{\sigma} \cong 1 + 3v$$
 and  $\frac{\epsilon_e \omega}{\sigma} \cong 9vX$ . (10)

In both these cases the dielectric constant expressed as a parameter  $\epsilon_{e}\omega/\sigma$  is very small compared to unity. However, if the film has an admittance of an intermediate value, the effective dielectric constant can be relatively much larger. In fact, its maximum value can be seen to occur when X=2 and is given by

$$\frac{\epsilon_e \omega}{\sigma} \bigg]_{\text{max}} \simeq 18v/17. \tag{11}$$

That is, in the macroscopic sense, the phase angle between the electric field and current density can be of the order of v radians for a suspension of film-covered conducting spherical particles if  $X \cong 2$ .

This mechanism is a possible explanation for the large dielectric constants that have been observed in soils at low radio frequencies.1,4

JAMES R. WAIT Natl. Bureau of Standards Boulder, Colo. Formerly at Univ. of Toronto Toronto, Ontario, Canada

<sup>4</sup> D. G. Frood, Radio Physics Lab., Ottawa, Ont., Can., unpublished work,

# The Gyrator in Dual Circuits\*

Dual circuits are planar circuits in which every mesh of one circuit can be paired off with an intersecting mesh of the other circuit, as illustrated by Fig. 1, and in which the voltages and currents in both meshes are related by:

$$(v_i - v_j) = \delta R_0 (I_i - I_j) \tag{1}$$

$$V_k - V_l = \delta R_0 (i_k - i_l) \tag{2}$$

$$v_i - v_j = Z(i_k - i_1) (3)$$

$$Z(V_k - V_l) = R_0^2(I_i - I_l)$$
 (4)

where  $\delta = \pm 1$ .

\* Received by the IRE, June 27, 1957.

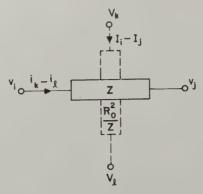


Fig. 1-Intersection meshes of dual circuits.

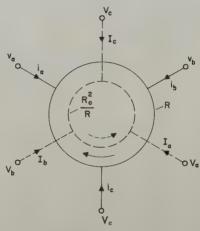


Fig. 2-Intersecting gyrators of dual circuits.

The purpose of this note is to indicate that the concept of dual circuits can be extended to circuits containing gyrators.

Consider the gyrator of Fig. 2, in which the voltages and currents are related by:

$$v_a - v_b = Ri_c$$

$$v_b - v_c = Ri_a$$

$$v_c - v_a = Ri_b.$$
(5)

Assume the existence of a dual gyrator, indicated by dotted lines in Fig. 2. The application of relations (1) and (2) to this assumed dual gyrator yields

$$(v_a - v_b) = \delta R_0 I_c, \text{ etc.}$$
 (6)

and

$$V_a - V_b = - \delta R_0 i_c, \text{ etc.}$$
 (7)

Combining (5), (6), and (7) we obtain

$$V_a - V_b = -\frac{R_0^2}{R} I_c$$
, etc. (8)

This last relation indicates that the impedance of the assumed dual gyrator is related to that of the original one by the same relations as for paired meshes in dual circuits, except that the handedness of a gyrator is opposite that of its dual. It follows that repeating the process of obtaining the dual gyrator reproduces the original gyrator. and that no contradiction will result from the assumption of the dual gyrator specified by (8).

MARCEL J. E. GOLAY Philco Corp. Philadelphia, Pa.

# Noisv and Noise-Free Two-Port Networks Treated by the Isometric Circle Method\*

The isometric circle method is a graphical method of transforming a complex variable by the linear fractional transformation.1 If the variable is a complex impedance Z, then the linear fractional tranformation

$$Z' = \frac{aZ + b}{cZ + d}, \qquad ad - bc = 1 \qquad (1)$$

can be interpreted as an impedance transformation through a bilateral, two-port network which, for a fixed frequency, is characterized by the four complex constants, a, b, c, and d.

The isometric circle is defined as the

circle which is the complete locus of points in the neighborhood of which lengths are unaltered in magnitude by (1). The isometric circle of the direct transformation,  $C_d$ , has its center at  $O_d = -d/c$  and a radius  $R_c = 1/|c|$ ; the isometric circle of the inverse transformation, Ci, has its center at  $O_i = a/c$  and the same radius.

Mathematically, transformation (1) is divided into two classes of transformations: the loxodromic transformation, characterized by a+d=complex, and the nonloxodromic transformation, characterized by a+d=real. The latter transformation is further divided into the hyperbolic, parabolic, and elliptic transformations specified by  $|a+d| \ge 2$ .

If the two isometric circles are drawn in the complex Z plane, Z=R+jX, the following graphical constructions yield a graphical method for transforming Z into Z' in the loxodromic case (see Fig. 1):

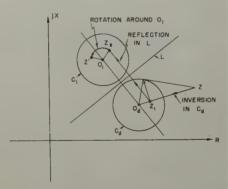


Fig. 1—The isometric circle method.

1) an inversion in the isometric circle of the direct transformation  $C_d$ ,  $Z \rightarrow Z_1$ ; 2) a reflection in the symmetry line L to the two circles,  $Z_1 \rightarrow Z_2$ ; and 3) a rotation around the center Oi of the isometric circle of the inverse transformation through an angle -2 arg (a+d),  $Z_2 \rightarrow Z'$ .

The different steps for performing the graphical constructions can be expressed in analytical form.2 Indicating a complex conjugate quantity by a star, we obtain

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1 L. R. Ford, "Automorphic Functions," 2nd ed., Chelsea Publishing Co., New York, N. Y.; 1951.

2 E. F. Bolinder, "The Isometric Circle Method in Analytical Form," Res. Lab. of Electronics, M.I.T., Quart. Prog. Rep., pp. 149–152, January 15, 1957.

$$Z_{1}^{*} = \frac{\frac{d^{*}}{c^{*}}Z + \frac{|d|^{2} - 1}{|c|^{2}}}{Z + \frac{d}{c}}$$

$$\equiv \text{ inversion in } C_{d}$$

$$Z_{2} = \frac{-\frac{a + d}{c}Z_{1}^{*} + \frac{|a|^{2} - |d|^{2}}{|c|^{2}}}{\frac{a^{*} + d^{*}}{c^{*}}}$$

$$\equiv \text{ reflection in } L$$

$$Z' - \frac{a}{c} = \left(Z_{2} - \frac{a}{c}\right)e^{-j2\arg(a+d)}$$
(2)

If the bilateral, two-port network is lossless, (1) takes the form

 $\equiv$  rotation around  $O_i$ 

$$Z' = \frac{a'Z + jb''}{jc''Z + d'}, \qquad a'd' + b''c'' = 1$$
 (3)

where a = a' + ja'', etc. Eq. (3) is a nonloxodromic transformation, and in this case the third operation given above is eliminated. We obtain

$$Z_1^* = \frac{d'Z - j\frac{d'^2 - 1}{c''}}{jc''Z + d'} \equiv \text{inversion in } C_d$$

$$Z' = Z_1^* - j\frac{a' - d'}{c''} \equiv \text{reflection in } L$$
(4)

A plotting of the isometric circles immediately specifies the nonloxodromic transformation. If the two circles intersect, the elliptic (above-cutoff) case exists; if the circles are tangent, the parabolic (cutoff) case exists; and, finally, if the two circles are external the hyperbolic (below-cutoff) case exists.

The isometric circle method has recently been applied to impedance transformations through both lossy and lossless bilateral, two-port networks.8-6 Often, especially when the radii of the isometric circles are large, it is convenient to use non-Euclidean hyperbolic geometry. It has been shown that for impedance transformations through lossless, bilateral, two-port networks the isometric circle method converts into two non-Euclidean reflections in two straight lines in the Cayley-Klein model of the two-dimensional hyperbolic space.7 Similarly, for impedance transformations through lossy, bilateral, two-port networks the isometric circle method converts into two non-Euclidean reflections in two straight lines in the Cayley-Klein model of the three-dimensional hyper-

<sup>3</sup> E. F. Bolinder, "Impedance Transformations by the Isometric Circle Method," Res. Lab. of Electronics, M.I.T., Quart. Prog. Rep., pp. 123–126; April 15, 1956.

<sup>4</sup> E. F. Bolinder, "Impedance and polarization-ratio transformations by a graphical method using the isometric circles." IRE TRANS., vol. MTT-4, pp. 176–180; July, 1956.

<sup>5</sup> E. F. Bolinder, "Some applications of the isometric circle method to impedance transformations through lossless two-port networks," Paper presented at the URSI-USA meeting, Washington, D. C., May 22–25, 1957.

<sup>6</sup> E. F. Bolinder, "Study of the Exponential Geometry," Acta Polytech., No. 214, Elec. Eng. Ser., vol. 7, 1957.

<sup>7</sup> E. F. Bolinder, "Graphical Methods for Transforming Impedances Through Lossless Networks by the Cayley-Klein Diagrams," Acta Polytech., No. 202, Elec. Eng. Ser., vol. 7, 1956.

bolic space.8 Finally, noisy two-port networks can be treated by extending the isometric circle method to three dimensions. so that a circle is extended to a hemisphere —a method that will be discussed later.

> E. FOLKE BOLINDER Res. Lab. of Electronics Mass. Inst. Tech. Cambridge, Mass.

<sup>8</sup> E. F. Bolinder, "Impedance transformations by extension of the isometric circle method to the three-dimension hyperbolic space," *J. Math. Phys.*, vol. 36, April 1957.
<sup>9</sup> E. F. Bolinder, "Geometric-Analytic Theory of Noisy Two-Ports," Res. Lab. of Electronics, M.I.T., Quart. Prog. Rep., July 15, 1957.

## Signal-Flow Graphs and Random Signals\*

In his interesting and important paper on signal-flow graphs and random signals,1 Huggins derives, among other results, a general expression for the correlation function of a train of pulses having a given form.

By considering separately the positive and negative ranges of the argument of the correlation function. Huggins is seemingly able to avoid the use of backward expectations and probability density functions in his analysis. However, upon a careful examination of the underlying assumptions, it appears that backward probabilities and expectations must be considered even when the argument  $\tau$  is restricted to positive values, and that the general expression given by Huggins is in need of some modification. The following analysis clarifies this point and, incidentally, provides an alternative and somewhat simpler method of obtaining a general expression for the correlation function of a train of pulses.

Consider the random signal generator shown in Fig. 1, in which, for simplicity,

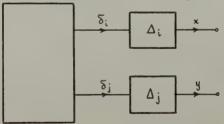


Fig. 1—Generation of the pulse trains x and y impulse trains  $\delta_i$  and  $\delta_j$ .

there are just two component function generators,  $\Delta_i$  and  $\Delta_j$ , with impulsive responses  $\Delta_i(t)$  and  $\Delta_j(t)$ , respectively. We shall not assume, as is done by Huggins, that  $\Delta_i(t)$  and  $\Delta_j(t)$  have a finite duration and vanish for negative t.

The component function generators  $\Delta_i$ and  $\Delta_i$  are "triggered" by events  $\epsilon_i$  and  $\epsilon_j$ , in the sense that at each occurrence of  $\epsilon_i$  an impulse is applied to  $\Delta_i$ , and at each occur-

\* Received by the IRE, June 25, 1957.

1 W. H. Huggins, Proc. IRE, vol. 45, pp. 74-86;
January, 1957.

rence of  $\epsilon_i$  an impulse is applied to  $\Delta_i$ . Thus, the inputs to  $\Delta_i$  and  $\Delta_j$  have the form of trains of impulses which will be denoted by  $\delta_i$  and  $\delta_j$ , respectively. Correspondingly, the pulse trains at the outputs of  $\Delta_i$  and  $\Delta_i$ will be denoted by x(t) and y(t).

Now the cross-spectral density of x(t)and y(t) is related to that of  $\delta_i$  and  $\delta_j$  by the well-known relation

$$\Phi_{x_iy_j}(s) = \Delta_i(-s)\Delta_j(s)\Phi_{\delta_i\delta_j}(s), \qquad (1)$$

where  $\Delta_i(s)$  and  $\Delta_i(s)$  denote the bilateral Laplace transforms of  $\Delta_i(t)$  and  $\Delta_i(t)$ , and  $\Phi_{\delta_i\delta_i}(s)$  denotes the cross-spectral density of the impulse trains  $\delta_i$  and  $\delta_j$ . Thus, the determination of  $\Phi_{x_iy_j}(s)$  is reduced to the calculation of  $\Phi_{\delta_i\delta_j}(s)$ .

To calculate  $\Phi_{\hat{o}_i\hat{o}_j}(s)$ , it is expedient to replace the impulses in  $\delta_i$  and  $\delta_j$  by narrow pulses of width dt and amplitude 1/dt, and then let dt approach zero. With reference to Fig. 2, it is seen that, for positive  $\tau$ , the

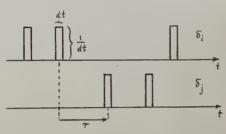


Fig. 2—Pulse train approximations to  $\delta_i$  and  $\delta_j$ .

correlation function of  $\delta_i$  and  $\delta_i$  is given by

$$\phi_{\delta_i \delta_j}(\tau) = \langle \delta_i(t) \delta_j(t+\tau) \rangle_{\text{Av}}$$

$$= \frac{1}{dt^2} p_{ij}(\tau) dt^2$$
(2)

where  $p_{ij}(\tau)dt^2$  is the probability of joint occurrence of  $\epsilon_i$  in the interval (t, t+dt) and  $\epsilon_j$  in the interval  $(t+\tau, t+\tau+dt)$ .

Now  $p_{ij}(\tau)$  is given by

$$p_{ij}(\tau) = p_i u_{ij}(\tau) \tag{3}$$

where  $p_i$  is the steady-state probability of occurrence of  $\epsilon_i$ , and  $u_{ij}(\tau)$  is the expectation density of the occurrence of  $\epsilon_i \tau$  seconds after the occurrence of  $\epsilon_i$ . Consequently,

$$\phi_{\delta_i\delta_i}(\tau) = \phi_i u_{ij}(\tau) \text{ for } \tau > 0$$
 (4)

and similarly

$$\phi_{\delta_i\delta_i}(\tau) = p_i u_{ii}(-\tau) \text{ for } \tau < 0.$$
 (5)

Eqs. (4) and (5) can be combined into the single equation

$$\phi_{\delta_i\delta_j}(\tau) = p_i u_{ij}(\tau) + p_j u_{ji}(-\tau)$$
 (6)

on the understanding that  $u_{ij}(\tau)$  and  $u_{ji}(\tau)$ are zero for negative  $\tau$ . Thus, the cross-spectral density, which is the bilateral La place transform of  $\phi_{\delta_i\delta_j}(\tau)$ , is given by

$$\Phi_{\delta_i\delta_j}(s) = p_i U_{ij}(s) + p_j U_{ji}(-s), \qquad (7)$$

where  $U_{ij}(s)$ , the Laplace transform of  $u_{ij}(\tau)$ , is the transmission (in signal-flow graph sense) from node i to node j.

The desired expression for  $\Phi_{x,yi}(s)$  can now be obtained by substituting  $\Phi_{\delta,\delta,}(s)$  in (1):

$$\Phi_{x_iy_i}(s) = \Delta_i(-s)\Delta_i(s) \left[ p_i U_{ij}(s) + p_j U_{ji}(-s) \right].$$
 (8)

More generally, when the signals x(t) and y(t) consist of additive combinations of the outputs of two or more component function generators, the expression for the cross-spectral density of x and y becomes

$$\Phi_{xy}(s) = \sum_{i} \sum_{j} \Delta_{i}(-s) \Delta_{j}(s) \left[ p_{i} U_{ij}(s) \right]$$

$$+ p_j U_{ji}(-s) ], \quad (9)$$

where i and j range over the indices of the component function generators of x and y,

respectively.

In piecing together the two parts of  $\phi_{\delta_i\delta_j(\tau)}$ , it should be noted that a delta function occurring in  $u_{ij}(\tau)$  at  $\tau=0$ , will also occur in  $u_{ji}(-\tau)$ . Hence, to avoid duplication it is necessary to split the delta function in two halves and associate one half with  $u_{ij}(\tau)$  and the other with  $u_{ji}(-\tau)$ . This is equivalent to replacing  $U_{ij}(s)$  in (9) with  $U_{ij}(s) - \frac{1}{2}$  whenever the corresponding  $u_{ij}(\tau)$  has a delta function at  $\tau=0$ .

The result expressed by (9) can be put into a different though equivalent form involving backward expectations. Thus, let  $v_{ij}(\tau)d\tau$  denote the conditional probability that  $\epsilon_i$  occurred in the interval  $(-\tau, -\tau - d\tau)$  given that  $\epsilon_j$  occurred at  $\tau = 0$ . Then  $v_{ij}(\tau)$  is the backward expectation density, which is related to the forward expectation density  $u_{ij}(\tau)$  by the equation

$$p_i u_{ij}(\tau) = p_j v_{ij}(\tau) \tag{10}$$

or, in terms of transmission functions,

$$p_i U_{ij}(s) = p_j V_{ij}(s), \tag{11}$$

where  $V_{ij}(s)$ , the Laplace transform of  $v_{ij}(\tau)$ , is the backward transmission function from i to j.

Thus, in terms of both forward and backward expectation densities, (9) can be written as

$$\Phi_{xy}(s) = \sum_{i} \sum_{i} \Delta_{i}(-s) \Delta_{j}(s) p_{i} [U_{ij}(s)$$

$$+ V_{ji}(-s)$$
]. (12)

In the foregoing analysis, we have not made use of the average message  $\overline{Y}_i(s)$  which plays a central role in the method employed by Huggins. Had we done so, we would have found the following expression for  $\overline{Y}_i(s)$ :

$$\bar{Y}_{j}(s) = \sum_{s} \Delta_{k}(s) \left[ U_{jk}(s) + V_{kj}(-s) \right] \quad (13)$$

which differs from that given by Huggins in the presence of the backward expectation term  $V_{kj}(-s)$ . Intuitively, this means that even when  $\tau$  is restricted to positive values, one cannot disregard the contributions to  $y(\tau)$  due to events which occurred prior to  $\tau=0$ .

It should also be noted that  $\Phi_{xy}(s)$  as given by (9) yields both the continuous and the discrete (line) components of the power spectrum. However, some care must be exercised in the use of (9) in order to obtain the discrete component. Specifically,  $\Phi_{\delta i,\delta_j}(\omega)$  [as given by (7)] should be regarded as the bilateral Fourier transform of  $p_i u_{ij}(\tau) + p_j u_{ji}(-\tau)$ , rather than as the sum of unilateral Laplace transforms of  $p_i u_{ij}(\tau)$  and  $p_j u_{ji}(-\tau)$ . For example, in the case of the Poisson process considered by Huggins,  $p_i = p_j = \lambda$ ,  $u_{ij}(\tau) = \delta(\tau) + \lambda$  for  $\tau > 0$ , and hence  $\phi_{\delta_i \delta_j}(\tau) = \delta(\tau) + \lambda$  for all  $\tau$ . Consequently,  $\Phi_{\delta_i \delta_j}(\omega) = 1 + \lambda \delta(\omega)$  and the spectral

density function is given by  $\Phi_{xy}(\omega) = \lambda + \lambda^2 \delta(\omega)$ , which exhibits a line of magnitude  $\lambda^2$  at  $\omega = 0$ .

L. A. ZADEH Dept. of Elec. Eng. Columbia University New York 27, N. Y.

#### Author's Comment<sup>2</sup>

The general expression (9) for the correlation function given by Zadeh is an important improvement upon the results of my paper in that it avoids the piecing together of partial solutions and thus eliminates a dangerous pitfall for the unwary. In particular, if in (20) of my paper, one uses the expected signal  $\bar{Y}_i(s)$  valid for all  $\tau$  by including the backward expectation given by Zadeh, there results

$$\bar{Y}_{j}(s) = \sum_{k} \Delta_{k}(s) \left[ U_{jk}(s) + \frac{p_{k}}{p_{j}} U_{kj}(-s) \right]. (23a)$$

and

$$\Phi_{xy}(s) = \sum_{j} p_j \Delta_j(-s) \bar{Y}_j(s)$$
 (20)

where the index j ranges over all symbols of the x signal. This expression is a correct representation of the correlation function for all  $\tau$  and the inconsistencies that I handled as the "negative- $\tau$  artifact" are avoided. In addition to making these changes in my paper, the interested reader should also replace (23b) by

$$\overline{X}_k(s) = \sum_j \Delta_j(s) \left[ U_{kj}(s) + \frac{p_j}{p_k} U_{jk}(-s) \right].$$
(23b)

With these changes suggested by Zadeh, the four paragraphs of my paper leading to (26) are unnecessary and should likewise be deleted. Fortunately, the artifact corrections led to the correct final results in each of the specific examples given in my original paper. I am indebted to Zadeh for showing how these difficulties can be avoided in an elegant and systematic way.

W. H. Huggins Johns Hopkins University Baltimore 18, Md.

<sup>2</sup>Received by the IRE, June 25, 1957.

#### How to Prepare a Talk\*

Several times, prior to speaking at IRE meetings, I have been thoughtfully supplied with a reprint of a generally admirable article, "How to Address the American Physical Society," by K. K. Darrow.

I agree with most of Dr. Darrow's remarks. I am sure that his advice "2) Write out your speech in advance and commit it to memory," and "3) If you cannot memorize your manuscript read it aloud," has led to many fine presentations; his own incom-

parable talks may serve as an example. I believe, however, that this is not the only way to deliver an acceptable talk, and indeed I doubt that it is the best way for most

My advice would be something as follows: First, think over what you have to say and make notes in the form of headings; second, go into a room, shut the door, note the time, and try to give the talk; third, think over points at which you have had difficulty, revise your notes, and rehearse difficult portions; fourth, repeat this process until you can give the talk smoothly and in the time allotted. This should not result in a fixed set of words.

I believe that following my prescription will result in a good talk, that it will help the speaker to answer questions, and that it will make it increasingly easy for him to

I realize that this matter may be controversial. After having received a reprint of Dr. Darrow's estimable remarks on several occasions, I feel like starting a controversy.

JOHN R. PIERCE Bell Telephone Labs. Murray Hill, N. J.

### An Extension of the Kelly Betting System to Binary Decision Feedback\*

A recent paper by Kelly¹ considers the transmission of the results of a chance situation over a one-way noisy communication channel, permitting a gambler to place bets at the original odds. The paper studies the exponential rate of growth of capital that results therefrom, and demonstrates that the maximum growth occurs at a rate equal to the capacity of the channel.

The following discussion extends the application of Kelly's approach to a two-way communication link involving binary decision feedback. In this system, the receiver has the option of rejecting the received signal as ambiguous and of requesting a repeat from the transmitter over an error-free feedback path. The decision process considered here uses two thresholds to define the region of ambiguity.

In showing the application of the Kelly method to the two-way case, the information rate of the binary decision feedback system is derived first. Let n be the average number of transmissions per message and let  $q_A$  be the probability that the finally accepted message is correct. In N transmissions there will be N/n accepted messages, each containing the information  $[1+q_A] \log q_A + (1-q_A) \log (1-q_A)]$ . Therefore, the information per transmitted symbol, I, is

<sup>\*</sup> Received by the IRE, June 24, 1957.

<sup>\*</sup> Received by the IRE, July 9, 1957. Supported by the Air Force Cambridge Res. Ctr, Air Res. and Dev. Comm., under Contract No. AF 19(604)1964.

¹ J. L. Kelly, Jr., "A new interpretation of information rate," Bell Sys. Tech. J., Vol. 35, pp. 917–926; July, 1956.

$$I = \frac{1}{N} \left( \frac{N}{n} \right) [1 + q_A \log q_A + (1 - q_A) \log (1 - q_A)]$$

$$= \frac{1}{n} [1 + q_A \log q_A + (1 - q_A) \log (1 - q_A)]. \quad (1)$$

Having derived the expression for information rate, we now obtain the expression for maximum rate of increase of capital in a betting situation a la Kelly. Assume that a noisy channel is reporting one of two outcomes to a gambler. If the received signal is ambiguous, the gambler asks for repetition. If the gambler rejects entirely the message on which repetition is requested (noncumulative case), there is no gain from the gambler's point of view as a result of using feedback. In this case, it is just as profitable for him not to bet at all on the uncertain event, but to wait instead for new information. If, on the other hand, he integrates the repeated digits until a certain probability threshold is reached (cumulative case), an advantage is gained. Let  $V_0$  be the initial capital,  $V_N$  the capital after N transmissions, and l the fraction of capital invested each time. Then,

$$V_N = (1+l)^{Nq_A/m} \cdot (1-l)^{N(1-q_A)/m} \cdot V_0$$

and

$$G_{\text{max}} = \max_{N \to \infty} \lim_{N \to \infty} \frac{1}{N} \log \frac{V_N}{V_0}$$
$$= \frac{1}{N} \left[ 1 + q_A \log q_A + (1 - q_A) \log (1 - q_A) \right].$$

the expression for the information rate of the binary decision feedback system.

Thus, it is seen that for the binary decision feedback system, as well as for the unidirectional system treated by Kelly, the maximum exponential rate of growth of capital is equal to the capacity of the channel.

J. J. METZNER AND L. S. SCHWARTZ College of Engineering New York University New York, N. Y

#### The Limits of Brainstorming\*

Having had some experience with brainstorming sessions, the writer wishes to compliment Mueller for his viewpoints. True enough, there is no great discovery or fabulous invention made by a body of brainstormers; however, without that body many theories and devices would still be uninvented, notwithstanding the fact that in the end there is generally only one solitary mind behind the result.

One of the greatest and most severe limitations to the mind of the trained scientist is *routine thinking*, a limitation unknown to the inventor of yesterday who scarcely went through high school. There are numerous known cases of a mind struggling with a difficult problem for a ten-year period or so,

\* Received by the IRE, June 20, 1957.

1 R. E. Mueller, PROC. IRE, vol. 45, p. 874; June, 1957.

and then, through the impetus of another mind, the concept of the missing link appears, and in a flash of unequalled excellence of mind the great discovery is made.

The true fact behind the resultant success of any brainstorming session, and particularly a brainstorming session in network theory, perhaps in network synthesis, appears to the writer to lie in the deep thinking ability of the individual in solitary confinement, assisted in his thinking by the routine-channel-breaking power of frequent brainstorming sessions. The individual thinker, trying to penetrate the unknown, is like a blind person, trying to find his way up to the top of the jungle gym. He can lift himself to higher and higher levels, but only if he becomes conscious of the existence of additional points of support. The brainstorming session has one function, in addition to the often overlooked psychological one, and that is to give the "blind climber" enough "inner light" to see new and perhaps unexpected "points of support," upon which all the mental forces of the keen mind can be concentrated.

Expanding on the psychological factor, not mentioned by Mueller, this writer feels that it is the intellectual competition, the *game factor*, which is responsible for the stimulance of the mind, making brainstorming sessions beneficial to mankind.

As is probably implied by Mueller, one million years of one million brainstormers cannot equal one flickering second's activity of the superior mind.

HARRY STOCKMAN Neutronics Research Co. Waltham, Mass

### An Improved Operational Amplifier\*

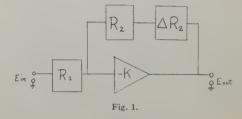
There are two operational errors to be considered in reference to Nitzberg's comment. The first, called computational error by Nitzberg arises from the fact that the internal amplifier gain or more exactly the loop gain is less than infinite. The proposed solution is to introduce an inner regenerative loop which might be adjusted to eliminate all computational error before each computation. For the case where the operational function is algebraic addition, the adjustment can more simply be made in the  $R_1$  and  $R_2$  components (i.e., the mixing or "beta" network). In this way the computational error can be eliminated without any need for adding an internal regenerative

The second error, which might be called drift error, is caused by change in values of the components due to aging and environmental influences. It is this error which frequently makes high amplifier gain a necessity. Over-all drift error can be stated as

$$E_d = \frac{A_d}{1 - (KB)_n (1 + A_d)}$$

\* Received by the IRE, June 27, 1957. 1 R. Nitzberg, Proc. IRE, vol. 45, p. 880; June, 1957. where  $A_d$  is the fractional drift error in the internal amplifier gain and  $(KB)_n$  is the nominal loop gain. It cannot be said that, in general, the addition of an internal regenerative loop will reduce this error. True,  $(KB)_n$  will be increased but because of the characteristic nature of many regenerative circuits,  $A_d$  will also be increased and the result can be a new over-all error  $E_d$  which is larger than it was before the addition of the regenerative circuit

There is a step which can be taken to reduce drift error where the internal errors  $A_d$ are expected to be distributed normally around zero (plus and minus). Note in the equation that for two fairly large equal values of Ad, one positive and one negative, the negative  $A_d$  will produce much the larger drift error  $E_d$ . The mixing network  $R_1$ , and  $R_2$  can be designed or adjusted in manufacture to introduce a small positive error in the over-all gain of such size that the ensuing positive and negative  $A_d$  will each produce the same size error with respect to the over-all nominal gain. This technique can be combined with that suggested in the first paragraph (see Fig. 1). Standard value mix-



ing network components are used, computational error is eliminated and the maximum probable drift error has been minimized.

A. Bossinger Senior Elec. Engr. Sperry Gyroscope Co. Division of Sperry-Rand Inc. Great Neck, N. Y.

#### Letter from Mr. Staudhammer<sup>2</sup>

In Nitzberg's article,<sup>2</sup> the approximate transfer functions of two analog computer diagrams are shown. Both computer connections are designed to result in a transfer function of  $-Z_2/Z_1$ . However, the transfer functions, excluding grid currents and loading effects for the two configurations, are, given erroneously. The computer diagrams and their transfer functions are repeated below (Figs. 1 and 2):

$$G = \frac{e_{\text{out}}}{e_{\text{in}}} = -\frac{Z_2}{Z_1} \frac{1}{1 + \frac{Z_2}{Z_1}}$$
(1)

or

$$G = -\frac{Z_2}{Z_1} \left[ 1 - \frac{1 + \frac{Z_2}{Z_1}}{K} + \cdots \right] \tag{2}$$

2 Received by the IRE, July 12, 1957.

$$G' = -\frac{Z_2}{Z_1} \frac{1}{1 + \frac{\left(1 + \frac{Z_2}{Z_1}\right)}{K_1} \left[\frac{1 + \frac{Z_a}{Z_b}}{K_2} - \frac{Z_a}{Z_b}\right]} (3)$$

or

$$G' = -\frac{Z_2}{Z_1} \left\{ 1 - \frac{1 + \frac{Z_2}{Z_1}}{K_1} \left[ \frac{Z_a}{Z_b} + 1 - \frac{Z_a}{Z_b} \right] + \cdots \right\} \cdot (4)$$

Since the desired transfer function is  $G_d = -Z_2/Z_1$ , the error in implementing  $G_d$  is as a first approximation

$$dG = \frac{Z_2}{Z_1} \left( 1 + \frac{Z_2}{Z_1} \right) \left( \frac{1}{K} \right)$$

for Fig. 1

Nitzberg correctly deduces the condition for  $G_d = G^1$ , namely the expression in the second brackets of (3) must vanish. This is met when

$$\frac{Z_a}{Z_b} = \frac{1}{K_2 - 1} \tag{5}$$

where evidently  $K_2 > 1$ .

However, it is not always possible to meet exactly the condition imposed by (5). Let us assume that a mismatch of the amount P is present. Then we must find the discrepancy in  $G^1$ ,  $dG^1$  which then will be a function of the mismatch P.

For this amount of impedance mismatch we have

$$\frac{Z_a}{Z_b} = \frac{1 - P}{K_0 - 1} \tag{6}$$

and

$$dG^{1}(P) = \frac{Z_{2}}{Z_{1}} \left( 1 + \frac{Z_{2}}{Z_{1}} \right) \left( \frac{1}{K_{1}} \right) \left( \frac{+P}{K_{2}} \right). \quad (7)$$

The object in going from a simple circuit of Fig. 1 to a more complicated circuit like Fig. 2 is either to reduce the error dG or to permit a  $dG^1$  as high (almost) as dG but by reducing the required gain K to some lower value  $K_1$ . Let us find the improvement possible with the circuit of Fig. 2. This improvement can be given as

$$\frac{\left|\frac{dG'}{dG}\right|}{\left|\frac{dG'}{dG}\right|} = \frac{\left|\frac{Z_2}{Z_1}\left(1 + \frac{Z_2}{Z_1}\right)\left(\frac{1}{K_1}\right)\left(\frac{+P}{K_2}\right)\right|}{\left|\frac{Z_2}{Z_1}\left(1 + \frac{Z_2}{Z_1}\right)\left(\frac{1}{K}\right)\right|}$$

$$=\frac{KP}{K_1K_2}.$$
 (8)

For a true improvement

$$\frac{\left|\begin{array}{c}dG'\right|}{\left|\begin{array}{c}dG'\right|} = \frac{KP}{K_1K_2} \ll 1\tag{9}$$

where we must not forget that K is (most usually) a very high number, and P should stand for the uncertainty in matching components [including drift of  $K_2$  as obtainable from (6)]. Since P can normally be small, (9) is satisfied if both  $K_1$  and  $K_2$  are highgain amplifiers. For example, let us find the necessary  $K_2$  for a 99 per cent reduction in

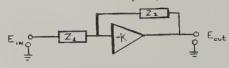


Fig. 1—G.

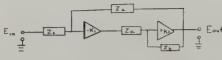


Fig. 2—*G'*.

error of a system with K = 50,000 if P = 5 per cent and  $K_1 = 1000$ . Eq. (8) yields

$$0.01 = \frac{50,000 \times .05}{1000 \times K_2}$$
 or  $K_2 = 250$ .

Thus it is obvious that a very large improvement can be made in going from circuit of Fig. 1 to circuit of Fig. 2. However, the price paid is one additional amplifier of positive gain, which in most computers is not available or can be obtained only by cascading two operational amplifiers, making three the total number of operational amplifiers used in Fig. 2.

JOHN STAUDHAMMER Dept. of Eng. University of California Los Angeles 24, Calif.

# Calculation of Inductance of Toroids with Rectangular Cross Section and Few Turns\*

#### Introduction

The measurement of magnetic permeability of ferrite ring samples at radio frequencies demands that the inductance of a toroid with the sample as a core be compared to the inductance of an identical toroid with an air core. It was found, in talking with various ferrite manufacturers, that at least one of them used for the latter value, the inductance calculated from the known dimensions, by application of a widely used, universally accepted formula.1 Another manufacturer's testing department used for the value of the air-cored toroid, the value measured, when the coil was wound on a polystyrene core. Investigation showed that these two approaches led to different results.

#### CIRCUMFERENTIAL INDUCTANCE

The accepted formula for the inductance of a toroid with rectangular cross section  $L = 0.0117 \times \text{thickness}$  (inches)  $\times n^2 \times \log_{10} r_2/r_1)\mu H$  is based upon a "current sheet" approach. It assumes that there are sufficient

\* Received by the IRE, May 16, 1956.

1 "Radio Instruments and Measurements," Circular C74, U. S. Dept. of Commerce, Natl. Bur. of Standards, p. 251, 1924.

turns to represent the current as a "sheet" whose value is  $n \times i$ . A correction can be made for the fact that there is winding space between turns. This correction leads to a reduction of the calculated inductance.2 Careful experiments have shown, however, that the measured inductance was always greater than that calculated. Table I shows this divergence. Although it is admitted that the measurements had many sources of error (e.g., lead inductance), it was found on careful examination that these errors could not account for the total error. It was suspected, particularly at low number of turns, that the contribution of the circumferential component of current to inductance might be significant. Measurements showed this to be so. We shall term this correction the "circumferential component" of toroid induct-

TABLE I

RATIO OF MEASURED INDUCTANCE TO CALCULATED
INDUCTANCE FOR VARIOUS TOROIDAL CORES

No.	Description	L measured L calculated
	All samples wound on 1.878 inches od ×1.404 inches id ×0.246 inch thick plexiglass cores.	
1)	194 turns no. 24 wire	1.37
2)	119 turns no. 20 wire	1.46
1) 2) 3)	56 turns, 16-inch copper	3.96
4)	10 turns, 5/16-inch copper strap	3.36
5)	10 turns, electro deposited on form with nearly constant 32-inch spacing between turns	2.88
6)	4 turns, electro deposited on form with nearly constant a-inch spacing between turns	12.20
7)	2 turns electro deposited on form with nearly constant \$\frac{1}{8}\$-inch spacing between turns	43.00

#### DESCRIPTION OF EXPERIMENTS

A number of rectangular cross section lucite rings were made whose dimensions were the same as those of a ferrite sample to be tested (1.878 inches od  $\times$ 1.404 inches id  $\times$ 0.246 inch thick). In the first experiments these were wound with various numbers of turns of either wire or strap, but it was soon realized that with such methods it was impossible to hold the winding to the dimensions of the core, giving the effect of a larger core cross section and, most certainly, lack of agreement with theory (see Appendix).

The next technique used was to paint the turns on the plastic form with Du Pont Number 4817 Silver Paint, then to copper plate on top of this to ensure good conductivity and a solderable surface for connections.

By this means, toroids were made with 10, 4, 2, and 1 turn having a nearly constant turn spacing of  $\frac{1}{16}$  to  $\frac{1}{8}$  inch between turns. Two varieties of a 1-turn toroid were made, one with two circumferential turns and the other with zero circumferential turns (*i.e.*, a split ring). It might be argued that the latter is not a toroid, and the writer would not greatly dispute it except that it represents

<sup>2</sup> F. W. Grover, "Inductance Calculations," D. Van Nostrand Co., Inc., New York, N. Y., p. 170; 1946. a limiting case. In addition to these, a 1-turn ring was made.

Measurements were carried out on a Boonton 160-A Q-meter over a range of frequencies and tuning capacitances, in order that the effects of stray capacitance could be evaluated by the well-known method of plotting wavelength squared vs tuning capacitance. The result is a straight line plot, although it was found that the experimental points did not always lie precisely on such a line, but showed considerable scattering. Rather than depend upon a graphical "guess" at the supposed plot, the average slope was computed from the experimental data and from this slope the inductance was calculated as follows:

$$Lo = \frac{\text{slope in meters}^2/\mu\mu\text{f}}{3.542} \mu \text{ henries}.$$

For each of the toroids tested the inductance value was also calculated. Finally the inductance of a single circumferential turn was measured, and that of the leads used was measured.

#### RESULTS

The results of these tests are shown in Table II. The true toroid coil measurements are given, but the split ring results showed too much scattering to be of any use.

too much scattering to be of any use. Columns A, B, and C of Table II give the various contributions due to toroidal, circumferential, and lead components. Column D gives the sum of these components. The last two columns give the value of L as determined by measurement. Lo is the dc value calculated from the slope of the  $\lambda^2$ -C plot, while the last column is the average value measured. It is noted that fair agreement exists between column D and the last two columns except in the last case. The reason supposed for the disagreement in that case is that a high leakage inductance may exist due to the unusual configuration. We may conclude, therefore, that for toroids of small numbers of turns the circumferential contribution is a large portion of the measured value. Consequently, for measurements of permeability of core materials, comparison must be made to the value of inductance calculated by the accepted formula quoted above.

#### APPENDIX

Effect of Variations in Core Cross Section on Inductance

If we have

$$L = 0.0117 \times t \times n^2 \times \log_{10} \frac{r_2}{r_1} \, \mu h$$

where t is the thickness in inches, n is the number of turns, and  $log_{10} r_2/r_1$  is the tenbase logarithm of the radius ratio, or

$$L = 0.2 \times t \times n^2 \times \ln \frac{r_2}{r_1} \, \mu h$$

with t the thickness in meters, n the number of turns, and  $\ln r_2/r_1$  natural logarithm of the radius ratio, we may investigate the effect of variations in  $r_2/r_1$  on inductance by taking the derivative. Denoting  $r_2/r_1$  by R we have:

TABLE II

Comparison of Measured Inductance and that Calculated by the Addition of Contributing Components

Sample No.	No. of turns	$egin{array}{c} A & & & & & & & & & & & & & & & & & & $	B Circum- ferential inductance (µh)	C Estimated lead inductance (µh)	Sum of A, B, and C (µh)	Value of <i>Lo</i> calculated from slope of λ <sup>2</sup> -C plot (μh)	Average value of measured L in frequency range of measurement (µh)
5	10	0.0362	0.0620	0.0112	0.1094	0.1041	0.1056
6	4	0.00580	0.0620	0.0067	0.0745	0.0707	0.0769
7	2	0.00145	0.0620	0.0020	0.0655	0.0622	0.0631
8	1	0.0003622	0.1240	0.0067	0.1311	0.2085	0.2152

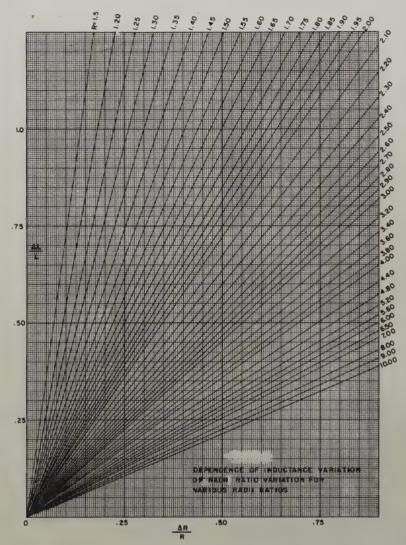


Fig. 1.

$$\Delta L = 0.2 \times t \times n^2 \times \frac{1}{R} \Delta R$$

and the decimal variation is

$$\frac{\Delta L}{L} = \frac{\Delta R}{R \ln R}.$$

In other words, since  $\ln$ , R is always less than 1, the percentage variation in L is considerably greater than the variation in R. This effect is shown in Fig. 1.

In the core samples tested, *R* was 1.338, hence the error caused by either mismeasuring the core diameter or by variations in di-

ameter (i.e., eccentricity) can be great. A 5 per cent error or variation in R will cause, in this case, a 17 per cent error in L.

In the case of thickness the situation is not so bad since L varies directly with t, and a certain per cent error in t will give the same per cent error in L. But this error is additive, and a 5 per cent variation in both t and R may yield an inductance error of 22 per cent.

RICHARD F. SCHWARTZ Moore School of Elec. Eng. University of Pennsylvania Philadelphia 4, Pa.

# Distribution Theory and the Strip

The following example may awaken some interest in the controversy for a full use and understanding of the remarkable theoretical help one can get from Schwartz's distribution theory.<sup>1</sup>

In many problems arising from the interaction of electromagnetic waves with an electron beam, one linearizes the solution by assuming that the physical quantities appearing in quadratic expressions are equal to the sum of a large dc and a small ac term. There is no difficulty when the ac forces on the electrons result in actions tangential to the dc trajectories (ordinary axial travelingwave tube, for instance). There is a slight difficulty, however, when the actions are normal to the dc trajectories (transverse traveling-wave tube, carcinotron). In this case, the ac actions displace the beam from its equilibrium, creating, at times, an accumulation of space charge where none existed at equilibrium and, possibly, removing, at times, the space charge completely from where it was at equilibrium.

The Schwartzian distribution theory permits obtaining the linear solution to this problem with simple rigor. In the more common case, the beam at equilibrium is coplanar (y=0) and the trajectories are colinear (parallel to the z axis). The dc spacecharge density is given by

$$\rho_0 = Q_0 \delta_0(y) \tag{1}$$

in which  $\delta_0(y)$  is Dirac's Delta function of the variable y placed at y equals zero. When the ac actions displace the beam to y equals d, the space charge density becomes:

$$\rho = Q_0 \delta_d(y). \tag{2}$$

One wishes to write

$$\rho = \rho_0 + \rho_1 \tag{3}$$

or

$$Q_0\delta_d(y) = Q_0\delta_0(y) + \rho_1. \tag{4}$$

Let one project (4) on the  $\Phi$  space (space of the class D of functions). Using the formula:

$$f(y) = \int_{-\infty}^{+\infty} f(y)\phi(y)dy \tag{5}$$

one obtains

$$\rho_1(\phi) = Q_0[\phi(d) - \phi_{(0)}]. \tag{6}$$

But d is small and  $\phi(y)$  is a well-behaved indefinitely continuous function which can be expended in Taylor series. The first term of the expansion yields:

$$\rho_1(\phi) = Q_0 d\phi^{I}_{(0)} \tag{7}$$

in which the Latin numeral is for order of differentiation.

However.

$$\begin{split} \phi^I_{(0)} &= \int_{-\infty}^{+\infty} \phi^I(y) \delta_0(y) dy \\ &= -\int_{-\infty}^{+\infty} \delta_0^I(y) \phi(y) dy = -\delta_0^I(\phi) \end{split} \tag{8}$$

hence:

$$\rho = Q_0 \delta_0(y) - Q_0 d \delta_0^I(y). \tag{9}$$

Eq. (9) is the rigorous linear expansion of  $\rho$ . The minus sign in (9) may surprise; the formalism used is, however, the only correct one and, of course, yields the usual Taylor series expansion when such expansion exists in common algebra.

In general, one can find that

$$\delta_d(y) = \sum_{0}^{\infty} \frac{d^n}{n!} (-1)^n \delta_0^N(y)$$
 (10)

(N for order of differentiation). In the same manner,

$$Y_d(y) = Y_0(y) - \sum_{0}^{\infty} \frac{d^{n+1}}{n+1!} (-1)^n \delta_0^N(y)$$
 (11)

in which  $Y_d(y)$  is Heaviside's step function of the variable y starting at y equals d.

The rest of the problem is usual. Basically, one integrates the complete inhomogeneous set of Maxwell's equations to which one has added Lorentz's force equation. There are a few remarks of interest. First, in the ballistic equations, the discontinuities in the fields, due to the infinite space charge density within the beam, do not appear because charges are not affected by their own fields. Second, in the case of dc-focusing fields which are functions of the normal coordinate y, the ac displacement of the beam creates an ac variation of the force on the electrons due to the focusing fields which adds to the ac variation of this same force due to the ac velocities. Third, when solving the inhomogeneous set of Maxwell's equations, one must not forget the ac variations of the Coulomb and magnetostatic fields produced by the beam itself due to the fact that the beam has been displaced. For instance, the dc-Coulomb field (in Gaussian units) is given by

$$Ey = -2\pi Q_0 + 4\pi Q_0 Y_0(y). \tag{12}$$

When the beam is displaced by d it becomes

$$Ey = -2\pi Q_0 + 4\pi Q_0 Y_d(y). \tag{13}$$

Using the Taylor series for  $Y_d$ , one obtains an ac contribution:

$$Ey = -4\pi Q_0 d\delta_0(y). \tag{14}$$

More trivial is the fact that the normal velocity of the electron is related to the normal excursion by

$$Vy = \frac{dd}{dt} \cdot \tag{15}$$

Finally, when all the different field contributions and the different current contributions are replaced in the inhomogeneous set of Maxwell's equations, one uses the property that the Dirac Delta function, its derivative, and ordinary functions cannot be of the same order of infinitude, so that each equation must be satisfied independently by the terms in which the Delta function appears, by the terms in which its derivative appears, and by the terms in which only ordinary functions appear.

PHILIPPE A. CLAVIER Zenith Radio Corp. Chicago 39, Ill.

# On the Use of Ferrites for Microwave Single-Sideband Modulators\*

With reference to the note by Kemanis¹ on the use of a rotating quarter-wave differential phase-shift section in the form of a suitably magnetized ferrite to produce single-sideband modulation with a loss of 3 db, it is not necessary to limit the argument to a differential phase shift of  $\pi/2$  radians in the section. In fact, a rotating section with any differential phase shift, when suitably used, could produce single-sideband modulation. The minimum loss attainable is dependent on the differential phase shift of the rotating section.

A simple equation deduced from circular polarization considerations gives the loss as

$$-20\log_{10} \left| \sin \frac{\theta}{2} \right| db$$

where  $\theta$  is the differential phase shift of the rotating section in radians. The losses of  $\pi$  and  $\pi/2$  sections are 0 and 3 db, respectively.

K. I. KHOURY Decca Radar Ltd. London, England

\* Received by the IRE, July 15, 1957.

G. Kemanis, "On the cotton-mouton effect in ferrites," Proc. IRE, vol. 45, p. 687; May, 1957.

# Figure of Merit of Resonance-Type Isolator\*

This note studies the figure of merit of a resonance-type isolator, shown by Lax.<sup>1</sup> Some further results are reported, which are:
1) The optimum front-to-back ratio is derived as a function of the ferrite geometry, and 2) Lax's optimum ratio is also derived when the optimum geometry of ferrite and small microwave power are assumed.

As is well known, microwave behavior of ferrite is described in the following differential equations

$$\frac{d\overrightarrow{M}}{dt} = \gamma(\overrightarrow{M} \times \overrightarrow{H}) - \lambda \frac{\overrightarrow{M} \times (\overrightarrow{M} \times \overrightarrow{H})}{(\overrightarrow{M} \cdot \overrightarrow{M})} \cdot (1)$$

$$\frac{d\overrightarrow{M}}{dt} = \gamma(\overrightarrow{M} \times \overrightarrow{H}) - \frac{\overrightarrow{M} - \overrightarrow{M}_0}{\tau}$$

$$+ \frac{|M|}{|H|} \frac{\overrightarrow{H}}{\tau} \quad (2)$$

Eq. (1) is called a Landau-Lifshitz type and (2), a Bloch-Bloembergen type.

In the resonance-type isolator in rectangular waveguide, effective tensor permeabilities  $\chi_{xx}$ ,  $\chi_{yy}$ , and  $\chi_{xy}$  are introduced as

$$m_{x} = \chi_{xx}h_{0x} - j\chi_{xy}h_{0y} m_{y} = j\chi_{xy}h_{0x} + \chi_{yy}h_{0y}$$
 (3)

where  $m_x$ ,  $m_y$ , and  $h_{0x}$   $h_{0y}$  are magnetizations

\* Received by the IRE, July 15, 1957.

1 B. Lax, "Frequency and loss characteristics of microwave ferrite devices," Proc. IRE, vol. 44, pp 1368–1386; October, 1956.

<sup>\*</sup> Received by the IRE, July 12, 1957.

1 P. A. Clavier, "The dirac delta function," Proc. IRE, vol. 44, p. 1877; December, 1956. (See Bibliography.)

and external magnetic components in x and y direction, respectively.

 $\chi_{xx}$ ,  $\chi_{yy}$ , and  $\chi_{xy}$  are calculated as follows if L-L type equation is employed:

and Weiss, but the author would like to add one more experimental result.3

Three slabs of magnesium manganese ferrite were tested at 2800 mc. The ferrite

$$\chi_{xx} = \frac{\gamma^{2}M(H_{a} + N_{y} - N_{z}M) + \lambda(j\omega + \lambda 1/\chi_{0} + N_{y})}{(j\omega + \lambda 1/\chi_{0} + N_{x})(j\omega + \lambda 1/\chi_{0} + N_{y}) + \omega_{r}^{2}}$$

$$\chi_{yy} = \frac{\gamma^{2}M(H_{a} + N_{x} - N_{z}M) + \lambda(j\omega + \lambda 1/\chi_{0} + N_{x})}{(j\omega + \lambda 1/\chi_{0} + N_{x})(j\omega + \lambda 1/\chi_{0} + N_{y}) + \omega_{r}^{2}}$$

$$\chi_{xy} = \frac{\gamma M\omega}{(j\omega + \lambda 1/\chi_{0} + N_{x})(j\omega + \lambda 1/\chi_{0} + N_{y}) + \omega_{r}^{2}}$$
(4)

where

 $H_a$  = static magnetic field applied in z direction

H=internal static magnetic field

M = magnetization due to static field

 $\chi_0 = M/H = \text{static magnetic susceptibility}$   $N_x = \text{demagnetizing factor in } x \text{ direction}$ 

 $N_y =$  demagnetizing factor in y direction

 $N_z$  = demagnetizing factor in z direction

 $\omega$  = operating frequency

$$\begin{aligned} \omega_{\gamma} &= \gamma \sqrt{(H_a + N_z - N_z M)(H_a + N_y - N_z M)} \\ &= \text{magnetic resonance frequency}. \end{aligned}$$

As Lax has derived by using perturbation theory, the optimum front to back ratio as a function of ferrite position, is given as

$$R = \frac{\sqrt{\chi_{xx}''\chi_{yy}''} + \chi_{xy}''}{\sqrt{\chi_{xx}''\chi_{yy}''} - \chi_{xy}''}$$
 (5)

where  $\chi_{xx}'$ ,  $\chi_{yy}''$ , and  $\chi_{xy}''$  are imaginary parts of the effective susceptibilities.

The ratio R is calculated as the following, when the incoming wave is on resonance.

$$R = \left(\frac{2\omega_r}{\lambda}\right)^2 \frac{1}{(1/\chi_0 + N_x)(1/\chi_0 + N_y)}.$$
 (6)

The optimum ratio as a function of slab geometry, is obtained as

$$R_{\rm m x} = \left(\frac{2\omega_r \chi_0}{\lambda}\right)^2 \tag{7}$$

when demagnetizing factors  $N_x$  and  $N_y$ equal zero. As the static magnetic field is applied transversally, i.e., in z direction, the optimum condition is achieved when a thin ferrite slab is so placed on the broad face of the rectangular waveguide that the flat plane of the slab is on the (x, y) plane.

As Bloembergen<sup>2</sup> has pointed out, two differential equations, i.e., L-L and B-B types, become equivalent, provided one takes

$$\lambda/\chi_0 = 1/\tau \tag{8}$$

where  $\tau$  means the same relaxation time as in the B-B type and this condition is achieved when the phenomenon is assumed in small-signal region. If this equation is introduced to (7), we have

$$R_{\text{max}} = (2\omega_{\tau}\tau)^2. \tag{9}$$

Though the result obtained in (6) seems a little bit different from the value Lax obtained, we now have the same expression.

The criterion we have for the optimum condition of the front-to-back ratio has been experimentally established by Fox, Miller,

<sup>2</sup> N. Bloembergen, "Magnetic resonance in ferrites," Proc. IRE, vol. 44, pp. 1259-1269; October, 1955.

positions were all 18 mm from the narrow wall. The width and the length were ground to 10.8 mm and 111 mm in all cases. The thicknesses of the three slabs were 7.2, 4.8, and 2.4 mm. The attenuations in two ways are shown in Fig. 1. From this experiment,

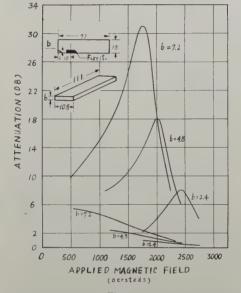


Fig. 1.

the front-to-back ratios were measured as 13, 15, and 20 for the slabs whose thicknesses were 7.2, 4.8, and 2.4 mm, respectively.

SYUITI HAYASI Matsuda Res. Lab. Tokyo-Shibaura Electric Co. Kawasaki, Japan

<sup>8</sup> S. Hayasi, S. Yoshida, T. Nagai, and K. Kurihara, to be published in *Toshiba Rev.*, Japan, 1957.

## The Elements of Nonreciprocal Microwave Devices\*

In the above article, Hogan describes the development of various types of load isolators and other nonreciprocal components.

In the discussion of resonance absorption

\* Received by the IRE, May 17, 1957; revised manuscript received, July 25, 1957.

¹ C. L. Hogan, Proc. IRE, vol. 44, pp. 1345–1368; October, 1956.

isolators, Hogan shows, in Figs. 23 and 27, bad and good ferrite configurations, and mentions that the one in Fig. 27, is especially suited for high powers and/or low frequen-

In this connection, it should be noted that the first practical resonance absorption isolator was described by Chait.2 Further, the important and, at first, surprising fact that the configuration of Fig. 27 has significant advantages over that of Fig. 23, was found through experiments in our organization in the spring and summer of 1954. The configurations of Hogan's Figs. 23 and 27 were first discussed as Figs. 4 and 6 in my paper.3

> JORGEN P. VINDING Cascade Research Corp. Los Gatos, Calif.

<sup>2</sup> H. N. Chait, "Non-reciprocal microwave components," 1954 IRE Convention Record, part 8, pp. 82–87.
<sup>8</sup> J. P. Vinding, "Microwave devices using ferrite and transverse magnetic field," 1955 IRE Convention Record, part 8, pp. 105–108.

#### A New High-Power Frequency Multiplier\*

The delicacy of electrode construction and the necessity for high current density are the two most difficult problems to be dealt with in extending the frequency of coherent oscillators into the submillimeter wave region. At this laboratory we have a great interest in the use of incoherent oscillations as a means of coping with the difficulties encountered in the coherent oscilla-

It is a well-known fact that high-frequency energy can be radiated from a dc discharge. We have found that in a microwave discharge, the frequencies of the output signals are integral multiples of the applied field frequency. Therefore, we will present the experimental results of this new phenomenon together with the possibility of developing a high-power and high-efficiency frequency multiplier in the submillimeter wave region.

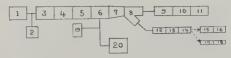
Margenau and Hartman<sup>1</sup> have shown that the distribution function in the microwave discharge assumes the form

$$f(a, v, t) = \sum_{l=0}^{\infty} P_l(a) \left\{ f_0^l(v) + \sum_{m=1}^{\infty} \left[ f_m^l(v) \cos m\omega t + g_m^l(v) \sin m\omega t \right] \right\}$$
(1)

where  $P_l(a)$  is the Legendre polynomial, degree l; t is time; v is electron velocity;  $\omega$  is the angular frequency of the applied field, and  $a = v_x/v$ . If (1) is true and if the phase of the vibrating electrons can be adjusted as desired, then a strong power at a particular frequency should be detected. We have tried to detect the harmonic components of

<sup>\*</sup> Received by the IRE, July 18, 1957.

1 H. Margenau and L. M. Hartman, "Theory of high frequency gas discharges. II," Phys. Rev., vol. 73, p. 309; February 15, 1948.



- Magnetron M312A
  3000-mc wavemeter
  Attenuator
  Unidirectional circuit
  Standing-wave detector
  Discharge cavity
  Tapered waveguide (from 3000 mc to 6000 mc)
  Switch
  High-pass filter
  Standing-wave detector
  Crystal mount or power meter
  High-pass filter

- High-pass filter
  Standing-wave detector
  10,000-mc wavemeter
  Variable attenuator
  Crystal mount or power meter
  High-pass filter

- Crystal mount Vacuum gauge Vacuum pump

Fig. 1—Block diagram of experimental apparatus.

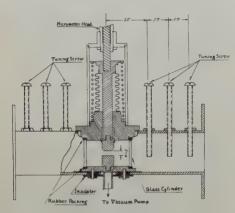


Fig. 2-Discharge cavity.

the applied field from the microwave discharge by utilizing an apparatus which was originally designed to measure the microwave breakdown voltage as shown in Fig. 1. A discharge cavity used in this experiment is shown in Fig. 2. A discharge gap composed of two cylindrical posts of 7-mm diameter is exposed in the low-pressure atmosphere, between 0.4-4 mm Hg. About 1000 volts at 50 cps is applied across the discharge gap to help initiate the microwave discharge. The output of a 3000-mc continuous-wave magnetron passes through the discharge cavity with about 3-mm gap length. The circuit impedance is controlled by six tuning screws so that a gap voltage equal to the breakdown voltage can be reached. After the discharge is started, the ac voltage is removed and the tuning screws and the gap length are readjusted to provide the best matching that can be obtained at the input circuit; at the same time, the maximum output of the particular harmonic component can be obtained. The output power is picked up through the highpass filter. The incident wave itself includes the harmonic components, but their levels are very low. The vswr in the magnetron output is kept smaller than 1.07 throughout the experiment.

The frequency of the output signal was measured, and it was found that the very strong signals, for which the frequencies were integral multiples of the applied field frequency, were the only possible ones to be detected by our apparatus whatever the pressure and the circuit conditions of the discharge cavity might be. The harmonic components measured were the second, third and fourth. The frequency of each harmonic was as follows:

> Applied field frequency 6070 mc, 9099 mc, 12,130 mc. Second harmonic Third harmonic Fourth harmonic

The errors of the frequencies of the second and fourth harmonics are within the error of the frequency meter used. The output frequency was constant over a wide change of pressure, although the output power changed considerably. From these facts, it is reasonable to conclude that the output frequency is exactly a harmonic of the driving field frequency. The output power of each harmonic component was a function of the circuit condition, the discharge gap length, and the pressure.

The output power of each harmonic component is compared with the maximum output power from the generator itself in Table I.

TABLE I

	Magnetron	Microwa ve Discharge
Fundamental Second harmonic Third harmonic Fourth harmonic	12.4 watts 1 mw 0.3 mw a few mw	60 mw 21 mw 0.6 mw

The output power was increased if the gap length was increased. After all conditions were adjusted to optimum, if the pressure was increased, the output was decreased. For a fixed gap length, power output decreases with increasing pressure. If power output-pressure characteristics are measured for different gap lengths, the maximum output powers are not obtained at the same pressures, but occur at lower pressures for larger gap lengths. According to our experimental results, the maximum output was obtained with a gap length of 4 mm, although this was the maximum possible length obtainable in our apparatus. Why the output power is increased as the gap length is increased is not clear, but it might be due to the loss of electrons resulting from decreased diffusion, while at the same time, the total number of electrons is increased. This fact is very important from the standpoint of electrode dimensions. It seems that effective harmonic radiation happens to occur around a special pressure-gap length condition that corresponds to the breakdown voltage minimum in the PL-V<sub>s</sub> curve, where P is the pressure, L is the gap length, and V, is the breakdown voltage. In general, the output power changed in proportion to the input power. The modulated waveforms of the incident wave and third harmonic were observed by the oscilloscope. Around the maximum output condition, the third harmonic waveform was almost exactly reproduced from the incident wave. However, when the output power was decreased due to the misadjustment of the circuit values and the pressure, the waveform was distorted and noise components appeared. By adjusting the tuning screws, the discharge domain could be moved from the discharge gap to the outside of it. In this case, no harmonic output was observed.

From the above mentioned experimental results, we know that a microwave discharge in the particular gas works as a highpower frequency multiplier. This frequency multiplier has the following features:

1) A large power input can be used.

2) The electrode construction is very simple and dimensions are much larger than those of the conventional type of microwave generator.

3) The efficiency of frequency conversion is better than that of the crystal fre-

quency multiplier.

It is clear that the harmonic signal radiation is not due to plasma oscillations. The amplitude of electron vibration should be much smaller than the gap length. Thus it is expected that the harmonic current flowing through the electrode surface is smaller than that in the middle part of the discharge gap. If this is true, the minimum current density necessary to extract appreciable power would be considerably smaller than that of the conventional type of generator. It is believed that this mechanism provides a great possibility for extending the generation of microwave power into the millimeter and submillimeter wavelength range.

The authors wish to express their appreciation to Professor E. M. Boone, Director of the Electron Device Laboratory, The Ohio State University, and to Dr. E. D. Reed, Bell Telephone Laboratories, for their suggestions and for reading and revising the

manuscript.

Michizo Uenohara, Michiyuki UENOHARA, T. MASUTANI, AND K. INADA Faculty of Engineering Nihon University Tokyo, Japan

## Comparison of Subtraction-Type and Multiplier-Type Radiometers\*

The operation of the Dicke radiometer and the two-receiver radiometer has been recently discussed by Goldstein, Tucker, and Graham.1,2 These two multiplier-type radiometers are superior in their stability to subtraction-type radiometers used in early work of detecting noise signals.8-6 The accuracy of a subtraction-type radiometer is dependent on the constancy of receiver gain in the time interval between the zero adjustment and the output observation. Gain changes or drift make periodic zero adjustments mandatory. However, this disadvantage of subtraction-type radiometers may be partially offset in some applications by the

\* Received by the IRE, July 25, 1957. This work was supported by the U. S. Air Force, Rome Air Development Center.

opment Center.

1 S. J. Goldstein, Jr., "A comparison of two radiometer circuits," Proc. IRE, vol. 43, pp. 1663–1666; November, 1955.

2 D. G. Tucker, M. H. Graham, and S. J. Goldstein, Jr., "A comparison of two radiometer circuits," Proc. IRE, vol. 45, pp. 365–366; March, 1957.

2 K. G. Jansky, "Directional studies of atmospherics at high frequencies," Proc. IRE, vol. 20, pp. 1920–1932; December, 1932.

4 G. Reber, "Cosmic static," Proc. IRE, vol. 30, pp. 367–378; August, 1942.

5 G. C. Southworth, "Microwave radiation from sun," J. Franklin Inst., vol. 239, pp. 285–297; April, 1945.

1945.

R. H. Dicke, "The measurement of thermal radiation at microwave frequencies," Rev. Sci. Instr., vol. 17, pp. 268-275; July, 1946.

higher sensitivity and by the simplicity of

It is the purpose of this letter to compare the thresholds of subtraction-type and multiplier-type radiometers and to establish rates of amplifier gain variations that result in nonessential, i.e., 3 db or less, threshold degradation of the subtraction-type radiom-

The first subtraction-type radiometer considered consists of a receiver with a square-law second detector, followed by a dc balancing or subtraction device, a lowpass filter, and an indicator, as shown in Fig. 1. The power spectrum  $G_1(f)$  of the detector output  $V_1$  is obtained from the relation listed by Lawson and Uhlenbeck7, assuming that both signal and noise have uncorrelated Gaussian amplitude distributions with zero mean and a flat input power spectrum of bandwidth a cps. Thus

$$G_1(f) = 2(\sigma_{\varepsilon}^2 + \sigma_n^2)^2 [\delta(f) + (\alpha - f)/\alpha^2]$$

where  $\sigma_s$  and  $\sigma_n$  are the rms values of signal and noise, respectively. The dc voltage component of the above spectrum is

$$(V_1)dc = \sigma_s^2 + \sigma_n^2.$$

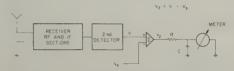


Fig. 1—Subtraction-type radiometer.

The reference voltage  $V_b$  is assumed to differ slightly from the part of  $(V_1)_{dc}$  that is due to system noise. In practice, this difference may be caused by gain variations or drift of the amplifier.  $V_b$  is defined by

$$V_b = \sigma_n^2 (1 - \epsilon)$$

where  $|\epsilon| < 1$ . The dc part of the output of the substraction circuit  $V_2$  is

$$(V_2)dc = \sigma_0^2 + \epsilon \sigma_n^2.$$

The power spectrum of  $V_2$  is

$$G_2(f) = 2(\sigma_s^2 + \epsilon \sigma_n^2)^2 \delta(f)$$
  
+ 
$$2(\sigma_s^2 + \sigma_n^2)^2 (\alpha - f) / \alpha^2.$$

The dc part of the output of the low-pass filter is considered as the signal, the ac part as the noise. Designating the half-power bandwidth of the low-pass filter by  $\gamma$ , i.e.,  $\gamma = 1/(2\pi RC)$  and restricting the consideration to cases where  $\gamma \ll \alpha$ , the indicated output signal power-to-noise power ratio is

$$\left(\frac{s}{n}\right)_0 = \frac{(\sigma_s^2 + \epsilon \sigma_n^2)^2}{(\sigma_s^2 + \sigma_n^2)^2} \frac{\alpha}{\pi \gamma}$$

For small signal-to-noise ratios, i.e.,

$$\sigma_s^2 \ll \sigma_n^2$$

the above ratio reduces to

$$\left(\frac{s}{n}\right)_0 \approx \frac{(\sigma_s^2 + \epsilon \sigma_n^2)^2}{\sigma_n^4} \left(\frac{\alpha}{\pi \gamma}\right).$$

Matching the reference voltage  $V_b$  to the dc output caused by noise,  $\epsilon = 0$  and

<sup>7</sup> J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals," M.I.T. Series, McGraw-Hill Book Co., Inc., New York, N. Y., vol. 24, p. 62; 1950.

$$\left(\frac{s}{n}\right) \approx \frac{\sigma_s^4}{\sigma_n^4} \frac{\alpha}{\pi \gamma}$$
.

Following Goldstein,1 the least detectable input signal is considered to produce a unity output signal-to-noise ratio.

This least detectable signal power is

$$\sigma_{ld}^2 = \sigma_n^2 \sqrt{\pi \gamma / \alpha}$$

Inaccurate reference voltage V<sub>b</sub> will result in erroneous signal indications, if  $\epsilon_{0n}^2$  is a sizeable fraction of  $\sigma_s^2$ . The lower are the signal levels to be detected, the closer are the tolerances imposed on the reference voltage  $V_b$ , or the smaller are the permissible fluctuations of gain e. Considering an error of the radiometer output equal to  $\sigma_{ld}^2$  to be tolerable,  $\epsilon$  has to satisfy  $|\epsilon| \sigma_n^2 \leq \sigma_{ld}^2$ .

This error in  $V_b$  may occur between the time the system is adjusted for zero balance and the time when the signal observation is made. The minimum time interval required for determining the signal presence depends on the low-pass filter bandwidth y. Finite observation time degrades the output signalto-noise ratio. The equation relating the signal-to-noise output ratio of the receiver for infinite observation time may be modified to take into account the finite time available between the balancing operation and the signal observation. The low-frequency noise output of the radiometer is not affected by the balancing operation. Noise can be assumed to be applied for an infinite time to the output meter, while the signal is applied only after the dc balance is established at time t = 0. The observation of the radiometer output is made at time t = T. The output peak signal power-to-average-noise power ratio is computed following the method given by Davenport.8 For small input signalto-noise ratios

$$\left(\frac{s}{n}\right)_0 = \frac{\sigma_s^4}{\sigma_n^4} \frac{\alpha}{\pi \gamma} (1 - e^{-2\pi \gamma T})^2.$$

For small input signal-to-noise ratios, the cross terms of noise and signal are negligible as compared with the noise constituting the low-frequency radiometer output fluctuations. These fluctuations are independent of observation time. The signal output has the same time dependency as the output of an RC low-pass filter with a step of voltage applied at t=0. For a given observation time T, the signal-to-noise ratio, is maximized if  $\gamma$  satisfies the relation  $\gamma = 0.2/T$ .

This can also be seen from a plot of the output signal-to-noise ratio for T constant shown in Fig. 2. The maximum signal-tonoise ratio is obtained as

$$\left[\left(\frac{s}{n}\right)_{0}\right]_{\text{max}} = 0.81\alpha T \sigma_s^4 / \sigma_n^4.$$

The least detectable signal gives unity output signal-to-noise ratio according to the convention established earlier. The least detectable signal for a given observation time T is, therefore

$$\sigma_{ld}^2 = 1.11(\alpha T)^{-0.5}\sigma_n^2$$
.

 $^8$  W. B. Davenport, Jr., "Correlator Errors Due to Finite Observation Intervals," M.I.T. Res. Lab. of Electronics Tech. Rep. No. 191; March 8, 1951.  $^9$  The same relation applies to Dicke and two-receiver radiometers assuming  $\gamma$  is much less than the input bandwidth  $\alpha$  or the pass band of the postdetection filter  $\beta$ .

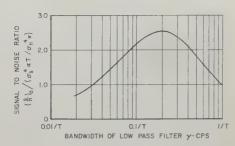


Fig. 2—The output signal-to-noise ratio as a function of the low-pass filter bandwidth for constant ob-servation time.

Using the above expression for  $\sigma_{ld}^2 \epsilon$  is related to T as

$$\frac{\mid \epsilon \mid}{T} \leq 1.11 (\alpha T^3)^{-0.5}.$$

The least detectable signal in time interval T for a zero drift system  $\sigma_{ld}^2$  and the drift rate that gives a maximum error equal to  $\sigma_{ld}^2$  in the detector output are shown in Fig. 3. Drift of the above magnitude may degrade the radiometer threshold by no more than 3 db. The maximum deterioration of the detection threshold occurs if the gain variation  $\epsilon$  is not uniformly distributed over the observation time T, but occurs as a step after the balancing has been performed. The step variation of the gain will give the 3-db threshold deterioration indicated above. Gradual gain changes have less effect on the radiometer threshold.

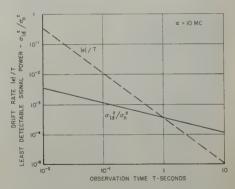


Fig. 3—The least detectable signal power and the permissible output drift rate as functions of observation time for a square-law detector radiometer.

The analysis of the radiometer using a linear detector follows the pattern of the preceding analysis. For zero drift  $(\epsilon = 0)$  and for small input signal-to-noise ratios, the linear detector gives the same signal-tonoise ratio as the square-law detector and hence the same least detectable signal power  $\sigma_{ld}^2$ . However, the drift rate that gives an error equal to  $\sigma_{ld}^2$  in the radiometer output using a linear second detector is one-half of the drift rate in a square-law detector radiometer. The amplifier gain variation or drift of the linear detector radiometer can be only one-half of the drift of the squarelaw detector radiometer for the same degradation in the reception thresholds.10

The least detectable signal powers of the Dicke, two-receiver, and subtraction-type

<sup>10</sup> Cf., W. H. Huggins and D. Middleton, "A comparison of the phase and amplitude principles in signal detection, *Proc. Natl. Electronics Conf.*, vol. 11, pp. 304-317; 1955; See p. 316, Fig. 5.

Chicago, Ill.

radiometers are all of the form

$$\sigma_{ld}^2 = \sigma_n^2 k \sqrt{\gamma/\alpha}.$$

The constants k have the following values

Dicke radiometer with sinusoidal modulation. 11

$$k = 2\sqrt{2\pi}$$
.

Dicke radiometer with square-wave modulation, 11

$$k = \pi \sqrt{\pi/2}$$
.

Two-receiver radiometer considering total signal power received, 11

$$k = \sqrt{2\pi}$$
.

 $^{11}$  The constants k given here differ from the corresponding constants listed by Goldstein (footnote 2) by a factor of  $\sqrt{\pi/2}$ . Goldstein considers an idealized flat low-pass filter. The above thresholds apply to a ingle-section RC low-pass filter.

Subtraction-type radiometer with driftless amplifiers,

$$k = \sqrt{\pi}$$
.

The thresholds of the radiometers considered differ by no more than 4.5 db. The subtraction-type radiometer exhibits the lowest signal threshold. If the output drift rate does not exceed the limit specified in Fig. 3, the subtraction-type radiometer is comparable in sensitivity with the other radiometers.

The equivalence of the sensitivites of the two types of radiometers has been checked experimentally. 12-The operation of the subtraction-type radiometers requires frequent checks of zero level of the output meter or recorder which can be done by periodically disconnecting the antenna. This superim-

12 Tests conducted by F. Splitt in Cook Research Labs., Chicago, Ill.

poses a square or trapezoidal wave over the output, that is easily distinguished from the gradual output changes caused by drift. The above radiometer operation resembles the operation of the Dicke radiometer, if the human operator is considered a substitute for the input modulator and the post detection band-pass filter.

The subtraction-type radiometers appear to merit consideration if the integration time is in the order of seconds or less. For longer integration times the stability requirements of the subtraction-type radiometers may make them more complex than the multiplier-type radiometers.

JANIS GALEJS
Appl. Res. Lab.
Sylvania Electric Products Inc.
Waltham, Mass.
Formerly at Cook Research Labs.

# Contributors\_

Rubin Boxer (S'49-A'49-M'55) was born in New York, N. Y., on August 6, 1927. He received the B.E.E. degree in 1949



R. Boxer

from Cooper Union and the M.E.E. degree from Syracuse University, Syracuse, N. Y., in 1955.

From 1949 to 1950, Mr. Boxer was a project engineer at the Wright Air Development Center, Dayton, Ohio. He was employed by the Rome Air (Development Center, Rome,

N. Y., from 1950 to 1955, where he was engaged in the development of control systems involving aircraft and guided missiles.

Since 1956, Mr. Boxer has been a staff engineer with Servomechanisms, Inc., Westbury, N. Y., concerned with the development of air data computers. He is the author of several publications in the fields of air traffic control., sampled data systems, and numerical methods.

He is an associate member of Sigma Xi.

\*\*

John J. Egli (A'47–SM'56) was born on October 22, 1911, in Teaneck, N. J. He received the B.S. degree in electrical engineering from Cooper Union in 1933, the E.E. degree from New York University in 1940, and graduate credit from Rutgers University in 1948. From 1929 to 1936, Mr. Egli was in the engineering department of the Mackay Radio and Telegraph Company, concerned

with radiotelegraph equipment design and installation. From 1936 to 1941, with the Commercial Products Department, of the



J. J. Egli

Bell Telephone Laboratories, he participated in the design of radio-broadcast equipment, magnetic tape records, and voder equipment.

Since 1941, Mr. Egli has been associated with the United States Army Signal Engineering Laboratories at Fort Monmouth, N. J. as chief

of the Deisgn and Construction Section of the Communications Engineering Branch; chief of the Radio-Relay and Microwave Section of the Radio Communication Branch; and at present is a specialist on matters pertaining to wave propagation and radio-systems engineering for the Spectrum Utilization Branch, Office of Technical Plans.

Mr. Egli is a member of Eta Kappa Nu.

\*

Joseph Feinstein (S'41–A'46–M'51) was born on July 8, 1925 in Brooklyn, N. Y. He received the B.E.E. degree from Cooper Union



J. FEINSTEIN

in 1944, the M.A. degree in physics from Columbia University in 1947, and the Ph.D. degree in physics from New York University in 1951.

He was employed by the Federal Telecommunications Laboratories from 1944 to 1946. From 1947 to 1949, he was an instructor at Brooklyn College. In 1949 he joined the National Bureau of Standards where he was engaged in work on radio propagation. Since 1954, he has been with Bell Telephone Laboratories, working on microwave tubes.

Dr. Feinstein is a member of Tau Beta Pi and the American Physical Society.

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For a biography and photograph of Wolfgang W. Gärtner, see page 699 of the May 1957 issue of PROCEEDINGS.

\*\*

Ross Gunn (A'35–SM'47–F'49) was born in Cleveland, Ohio, in May, 1897. He received the B.S.E.E. and M.S. degrees in



R. Gunn

electrical engineering at the University of Michigan, Ann Arbor, Mich., in 1920 and 1921, respectively, and the Ph.D. degree in physics from Yale University, New Haven Conn., in 1926.

Dr. Gunn was an instructor in engineering physics at the University of Michigan from 1920 to 1922.

In 1922 and 1923, he was radio research engineer for the U. S. Air Service. From 1923 to 1927, he was an instructor in the Physics Department of Yale University and in charge of the high-frequency laboratory during 1926 and 1927.

In 1927, Dr. Gunn joined the Naval Research Laboratory where he was superintendent of both the Mechanics and Electricity Division and the Aircraft Electrical Research Division, technical adviser to the Naval Administration, and technical director of the Army-Navy Precipitation Static Project. In 1946 he became Superintendent of the Physics Division and Technical Director of the Army-Navy Atmospheric Electricity Research Project.

In 1947 Dr. Gunn transferred to the U. S. Weather Bureau as the Director of the Physical Research Division and has since been made the Director of their Office of Physical Research. In 1955 he became the Assistant Chief of Bureau for Technical

Dr. Gunn has invented a number of basic electrical instruments; he holds more than 40 U. S. patents. He initiated the Navy's isotope separation and nuclear submarine program. He was cited by the Secretary of the Navy in September, 1945, for Exceptionally Distinguished Service. In 1951, Dr. Gunn was given the Distinguished Service Award of the Flight Safety Foundation. He received the 1956 Robert M. Losey award of the Institute of Aeronautical Sciences and the Department of Commerce Gold Medal for Exceptional Service.

Dr. Gunn is a member of the National Academy of Sciences and a Fellow of the

American Physical Society.

R. C. Honey (S'48-A'53) was born in Portland, Ore., on March 9, 1924. He received the B.S. degree in physics from the



R. C. HONEY

from Stanford University in 1950 and 1953 respectively. He served as a

radio technician in the U.S. Navy until 1946 and was a member of the local oscillator microwave project at Stanford University Electronics Research Laboratory from 1948 to 1952. Since 1952, he has been with the Microwave Group of Stanford Research Institute.



E. M. T. Jones (S'46-A'50-SM'56) was born in Topeka, Kans., in 1924. He received the B.S. degree in electrical engineering from



E. M. T. Jones

Swarthmore College in 1944 and the M.S. and Ph.D. degrees in electrical engineering from Stanford University in 1948 and 1950, respectively. Dr. Jones was a radar maintenance officer in the U.S. Navy from 1944 to 1946. From 1948 to 1950 he was a research associate at

Stanford University, working on the microwave local oscillator project. Dr. Jones joined the staff of Stanford Research Institute in 1950 where he is assistant head of the microwave group of the Antenna Systems Labo-

He is a member of Sigma Tau and RESA.

B. Kazan was born in New York, N. Y. on May 8, 1917. He received the B.S. degree in physics from the California Institute of



B. KAZAN

Technology in 1938 and the M.A. degree in physics from Columbia University in 1940.

He joined the Signal Corps Engineering Laboratories in 1940 and was engaged in early experimental work with radar equipment. From 1944 to 1950, he was chief of

the Special Purpose Tube Section at the Evans Signal Laboratory, where he was responsible for development and application engineering of traveling-wave tubes, klystrons, display tubes, and transistor devices. Since 1951, Mr. Kazan has been engaged in research on television tubes and display devices at the RCA Laboratories, Princeton,

Mr. Kazan is a member of the American Physical Society, Sigma Xi, and Tau Beta Pi.

Gordon S, Kino (S'52-A'54) was born on June 15, 1928, in Melbourne, Australia. He received the B.Sc. degree in mathematics in



G. S. KINO

1948 and the M.Sc. degree in mathematics in 1950 from London University. In 1955, he received the Ph.D. degree in electrical engineering from Stanford University.

He joined the Mullard Radio Valve Co., Salfords, Surrey, England, in 1947 as a managerial apprentice. In 1948, he became a

member of the Mullard Vacuum Physics Laboratory, where he was engaged in research on microwave triodes, traveling-wave tubes, and klystrons.

From 1951 to 1955, he was employed as a research assistant at the Electronics Research Laboratory of Stanford University, Stanford, Calif., where he carried out research on traveling-wave tubes and electromagnetic theory. He then worked as a research associate of the Microwave Laboratory at Stanford on electromagnetic theory.

He was a member of the technical staff of the Bell Telephone Laboratories, Murray Hill, N. J., where he was associated with the Electron Tube Development Department and carried out research on magnetrons. Dr. Kino returned to Stanford in February, 1957.

Dr. Kino is a member of Sigma Xi.



# IRE News and Radio Notes\_

#### PGME Begins Testing Program

The Buffalo-Niagara Chapter of the IRE Professional Group on Medical Electronics has launched a local program to make some modern electronic techniques available to Niagara Frontier medical research institutions. Under the plan, local electronic instrument manufacturers develop new instrument prototypes at their own expense. The medical research institutions then use the instruments in their laboratories for a trial period and perform gratis any necessary tests. If the instrument proves useful to the medical men, the instrument company then builds a final model of the tested prototype which the medical research institution can purchase at a nominal price if it wishes.

This plan for cooperation between electronic companies and medical research groups was the idea of Wilson Greatbatch, former Chairman of Buffalo-Niagara PGME, now of Taber Instrument Corporation; the present co-chairmen of the Buffalo-Niagara PGME, Robert Cohn, of the Chronic Disease Research Institute; and Godfrey Buranich of Bell Aircraft Corp.

Medical institutions which benefit from this program are the Chronic Disease Research Institute, the University of Buffalo Medical School and Children's Hospital.

Some of the instruments developed as a result of the cooperative effort include the first fully transistorized electrocardiograph, a transistorized decade amplifier for amplifying nerve currents and a complete medical electronic telemetering system for multichannel data recording on a single channel.

#### RETMA CHANGES NAME TO EIA

The Radio-Electronics-Television Manufacturers' Association has changed its name to the Electronic Industries Association. The new name was selected as being more representative of the expanding industry which the association serves.

The change in name will become effective upon approval of a charter revision by the

state of Illinois.

#### EIC CONFERENCE SET FOR DEC.

The 1957 Eastern Joint Computer Conference will be held at the Sheraton Park Hotel, Washington, D. C., December 9-13. The conference will be devoted to the problems which arise in the design and application of computers which are required to perform their job within a specified time cycle. Advance registrations may be obtained from R. T. Burroughs, IBM Corp., 1220 19 St., N.W., Washington, D. C. for \$4.00. After November 25, the registration fee, paid either by mail or at the conference, will be \$5.00.

Among the topics to be discussed at the conference will be industrial control computers and instrumentation, traffic control, navigation and surveillance, simulation in real-time, synthesis of real-time systems, on-line business systems, digital communications techniques, document reading, pattern recognition and output devices. Exhibits will also be on display. The IRE, the Association for Computing Machinery, and the AIEE are sponsors; the National Simulation Council is also participating.

#### Call for Papers

## NOVEMBER 1 IS DEADLINE FOR 1958 IRE NATIONAL Convention Papers

The 1958 IRE National Convention will be held at the Waldorf-Astoria Hotel and New York Coliseum, New York City, March 24-27, 1958. Prospective authors are requested to submit all of the following by Novem-

ber 1, 1957.

(1) 100-word abstract in triplicate, title of paper, name and address;

(2) 500-word summary in triplicate, title of paper, name and address; and an indication of the technical field in which the paper falls.

The technical fields which may be covered are: Engineering Management

Aeronautical & Navigational

Electronics

Antennas and Propagation

Audio

Automatic Control

Broadcast & Television Receivers

Broadcast Transmission Systems

Circuit Theory

Communications Systems

Component Parts

Education

Electron Devices

Electronic Computers

Industrial Electronics Information Theory Instrumentation Medical Electronics Microwave Theory & Techniques Military Electronics Nuclear Science Production Techniques Reliability & Quality Control Telemetry & Remote Control Ultrasonics Engineering

Engineering Writing and Speech

Vehicular Communications Address all material to: G. L. Haller, Chairman

1958 Technical Program Committee, The Institute of Radio Engineers, 1 East 79 St., New York 21, N.Y.

#### Calendar of Coming Events and Authors' Deadlines

Nat'l Electronics Conference, Hotel Sherman, Chicago, Ill., Oct. 7-9

1957 Convention of Audio Eng. Soc., Trade Show Bldg., New York City, Oct. 8-12

Computers in Control Symp., Chalfonte-Haddon Hall Hotel, Atlantic City, N. J., Oct. 16-18

IRE Canadian Convention Exhibition Park, Toronto, Can., Oct. 16-18

Conf. on Eng. Writ. Speech, Sheraton-McAlpin Hotel, New York City, Oct.

International Conf. on UHF Circuits, Paris, France, Oct. 21-26

Computer Applications Symp., Hotel Sherman, Chicago, Ill., Oct. 24-25 East Coast Aero. & Nav. Conf., Lord

Baltimore Hotel & 5th Reg. Armory, Balt., Md., Oct. 28-30

PGED Meeting, Shoreham Hotel, Wash., D. C., Oct. 31-Nov. 1

PGNS Annual Meeting, Henry Hudson Hotel, New York City, Oct. 31-Nov. 1

Annual Symp. on Aero Commun., Hotel Utica, Utica, N. Y., Nov. 6-8 Radio Fall Meeting, King Edward Ho-

tel, Toronto, Can., Nov. 11-13 PGI Conference, Atlanta-Biltmore Ho-

tel, Atlanta, Ga., Nov. 11-13 Mid-America Electronics Convention, Kan. City Mun. Audit., Kan. City,

Mo., Nov. 13-14 New England Radio Eng. Mtg., Me-chanics Bldg, Boston, Mass., Nov. 15-16

Conf. on Magnetism, Sheraton-Park

Hotel, Wash., D. C., Nov. 18-21

Elec. Computer Exhibition, Olympia,
London, England, Nov. 28-Dec. 4

PGVS Conf., Hotel Statler, Wash.,
D. C., Dec. 4-5

Eastern Joint Computer Conf, Park-Sheraton Hotel, Wash., D. C., Dec.

Nat'l Symp. on Reliability & Quality Control, Statler Hotel, Wash., D. C., Jan 6-8, 1958

Transistor-Solid State Circuits Conf., Phil., Pa., Feb. 20-21

Nuclear Eng. and Science Congress, Palmer House, Chicago, Ill., Mar. 16-21

IRE Nat'l Convention, N. Y. Coliseum and Waldorf-Astoria Hotel, New York City, Mar. 24-27 (DL\*: Nov. 1 G. L. Haller, IRE Headquarters, New York City)

Instruments & Regulators Conf., Univ. of Del., Newark, Del., March 31-Apr. 2

SW Regional Conf. & Show, Mun. Audit., San Antonio, Tex., Apr. 10-12 Conf. on Automatic Techniques, Statler

Hotel, Detroit, Mich., Apr. 14-16 Elec. Components Symp., Los Angeles,

Calif., Apr. 22-24 Seventh Region Conf. & Show, Sacra-

mento, Calif., Apr. 30-May 2 Western Joint Computer Conf., Ambassador Hotel, Los Angeles, Calif., May 6-8 (DL\* Jan. 15, P.O. Box 213,

Claremont, Calif.) \* DL = Deadline for submitting ab-

# ACTIVITIES OF THE IRE SECTIONS AND PROFESSIONAL GROUPS



G. H. Knight (left) presents John Ryder, 1955 IRE President, and J. J. Gershon with their commissions as Admirals in the Great Navy of Nebraska as J. C. Jensen (right) looks on. Dr. Jensen, teacher and department head at Nebraska Wesleyan University for 50 years, was a 1957 IRE Fellow Award winner.



1957 Aeronautical and Navigational Electronics Pioneer Awards were conferred on Dr. Lawrence A, Hyland (left) and posthumously on Dr. Alessandro Artom, whose award is accepted by his sons, Barone Dr. Guido Artom (second from left) and Barone Dr. Emilio Artom (right), Brig. Gen. Pete Sandretto (second from right), Chairman of PGANE Awards Committee announced the awards at the Banquet of the Ninth Annual National Conference on Airborne Electronics at Dayton, Ohio on May 14, 1957.



The Albuquerque-Los Alamos IRE Section recently held a competition in conjunction with the New Mexico Science Fair and awarded a \$200 scholarship to Royce Fletcher (right). S. C. Hight (left), R. K. Moore, and W. W. Granneman served on the Section's Scholastic Awards committee.



Recipients of Los Angeles IRE Section Awards at the annual meeting are shown above (left to right, standing): Willis Ware, Ellis King, Maurice Kennedy and E. C. Bertolet. Seated—Willard Fenn, W. E. Peterson, and M. L. Swan.



New and retiring officers of the IRE Northwest Florida Section and the new Fort Walton Chapter of the IRE Professional Group on Military Electronics surround honorary Chapter Chairman E. P. Mechling, Maj. Gen., USAF, Commander, Air Force Armament Center. Left to right: W. W. Gamel, Canoga Corp., past Section Secretary-Treasurer and incoming Vice-Chairman; J. J. Niedrauer, Bell Air-

craft, Chapter Organizer and first Chapter Chairman; First Lieut, W. F. Kirlin, USAF, AF Armament Center, Section and Chapter Secretary-Treasurer; General Mechling; E. F. Sapp Jr., Vitro Corp., Chapter Vice-Chairman; G. C. Flening, Eglin Proving Ground, past Vice-Chairman and incoming Chairman of the Section; and F. E. Howard Jr., AF Armament Center, retiring Section Chairman.

#### MARS RADIO ANNOUNCES ITS OCTOBER SCHEDULE AND TOPICS

The Air Force MARS Eastern Technical Net, which broadcasts over the air every Sunday afternoon at 2 p.m. (EDT) on 3295 and 7540 kc, announces its guest speakers for October: October 6—E. H. Shively, Dielectric Products Engineering Co. Topic: Antennas for vhf and uhf. October 13—G. W. Bailey, IRE Executive Secretary. Topic: Services of the IRE. October 20—Leonard Kahn, Kahn Research Lab. Topic: Compatible side band. October 27—Edward Tilton, ARRL. Topic: The world above 50 megacycles.

#### Conference on Magnetism Adds Another Day to its Program

The 1957 Conference on Magnetism and Magnetic Materials will be held at the Hotel Sheraton-Park, Washington, D. C., November 18–21. Because of the general interest shown in the conference as evidenced by the large number of contributed papers, its duration has been extended from three days to four.

The program of the conference is designed to emphasize topics of current interest in magnetism. A number of invited papers will survey past developments as well as give the latest progress in such fields as maser devices, garnets and other new magnetic materials, ferromagnetic resonance effects, magnetic properties of thin films, and magnetic annealing. Contributed papers cover a wide variety of topics related to magnetism and magnetic materials.

#### **OBITUARIES**

William B. Cowilich, former Assistant Secretary of the IRE, died on August 3rd as a result of injuries sustained in an automobile accident two days before.

Mr. Cowilich, who was born April 10, 1906, served as IRE Assistant Secretary during the period 1942–1944. In this capacity he was in charge of IRE headquarters operations in New York City. For the past 12 years he was sales representative for the Cleworth Publishing Co., a publisher of trade magazines, in Cos Cob, Conn.

John F. Farrington (A'19-M'29-F'31) died suddenly July 5 at his summer place at Centre Harbor, N.H. at the age of 62.



J. F. FARRINGTON

Mr. Farrington, after graduating from Bliss Electrical School in 1916, had entered the employ of the Western Electric Co. in New York in the radio research department. He took an active part in the development of radiotelephone equipment for the Army, Navy, and Air Force

in World War I. He participated in much of the radio research and development work

## MISCELLANEOUS IRE PUBLICATIONS

The following issues of miscellaneous publications are available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, New York, at the prices listed below:

Publications	Price per Copy
Component Symposiums	
Proceedings of the 1954 Electronic Components Symposium, May 4-6, 1954, Washington, D. C.	\$4.50
Proceedings of the 1957 Electronic Components Symposium, May 1-3, 1957, Chicago, Ill.	5.00
Electronic Computer Conferences	
Proceedings of the Joint AIEE-IRE-ACM Western Computer Conference, February 11–12, 1954, Los Angeles, Calif.	3.00
Proceedings of the Joint AIEE-IRE-ACM Western Computer Conference, March 1–3, 1955, Los Angeles, Calif.	3.00
Proceedings of the Joint AIEE-IRE-ACM Western Computer Conference, February 7–9, 1956, San Francisco, Calif.	3.00
Proceedings of the Joint AIEE-IRE-ACM Western Computer Conference, February 26–28, 1957, Los Angeles, Calif.	4.00
Review of Electronic Digital Computers, Joint AIEE-IRE Computer Conferences, December 10–12, 1951, Philadelphia, Pa.	3.50
Proceedings of the Joint AIEE-IRE-ACM Eastern Computer Conference, December 8–10, 1954, Philadelphia, Pa.	3.00
Proceedings of the Joint AIEE-IRE-ACM Eastern Computer Conference, November 7–9, 1955, Boston, Mass.	3.00
Proceedings of the Joint AIEE-IRE-ACM Eastern Computer Conference, December 10–12, 1956, New York, N. Y.	3.00
Magnetic Amplifiers Conference	
Proceedings of the Conference on Magnetic Amplifiers, April 5–6, 1956, Syracuse, N. Y.  Reliability & Quality Control Symposiums	4.00
Proceedings of the National Symposium on Quality & Reliability in Electronics, November 12–13, 1954, New York, N. Y.	5.00
Proceedings of the Second National Symposium on Quality & Reliability in Electronics, January 9–10, 1956, Washington, D. C.	5.00*
Proceedings of the Third National Symposium on Quality Control & Reliability	3.00
in Electronics, January 14–16, 1957, Washington, D. C.  Telemetering Conference	5.00
1953 National Telemetering Conference, May 20–22, 1953, Chicago, Ill.	2.00

<sup>\*</sup> IRE member rate—\$3.00.

of the Western Electric Co. and Bell Telephone Laboratories up to 1929, including work on transoceanic radiotelephone circuits, short-wave transmission, and shipshore radio. In 1929 he joined the IT&T Co. in charge of radio development. From 1934 to 1939 he was associated with the Hazeltine Corporation, and from 1941 until his death he worked for the Raytheon Company where he served as manager of the circuit development department at the Bedford Laboratory.

His experience covered all phases of radiotelephony since its practical beginning, and included transmitters, receivers, radio transmission, and military equipment. He was one of the authorities on electronic receiver circuits, and he had secured over fifty U.S. patents.

He had served on the IRE Admissions Committee, and New York Program Committee during part of his New York residence.

James Leslie Finch (A'19-M'28-SM'43-F'54), assistant chief engineer for RCA

Communications, Inc., died recently after a long illness.

A graduate of the University of Washington, Mr. Finch joined the General Electric Co. in 1915 and worked with E. F. W. Alexanderson, inventor of the longwave alternator. In World War I he served as the executive officer of the United States Naval radio station at New Brunswick, N. J., in charge of maintenance and technical operation of the first Alexanderson alternator.

Mr. Finch joined RCA in 1920. He received many honors, including the Gold Cross for Meritorious Service from Poland for his work in establishing that country's first transmitting station in 1924.

Mr. Finch designed the mountaintop radio transmitting antenna at Haiku, Hawaii, for the Navy and the antenna system for the Navy's giant radio station at Jim Creek, Wash. At the time of his death, Mr. Finch held sixty-four United States patents on communications and electronics inventions, all assigned to RCA.

He had specialized in Alexanderson radio equipment and transmitter design.

## Books\_

#### Electrical Measurements and Their Applications by W. C. Michels

Published (1957) by D. Van Nostrand Co., Inc., 257 Fourth Ave., N. V. 10, N. Y. 320 pages +2 appendix pages +9 index pages +viii pages. Illus.  $9\frac{1}{4}\times 6\frac{1}{4}$ , \$6.75.

This book is a successor to Advanced Electrical Measurements by W. R. Smythe and W. C. Michels. It is a textbook for college students and contains instructions for experiments as part of the text. In some places, important points regarding a measurement are discussed only in these experiment instructions, so these should not be skipped by the nonstudent reader.

The first part of the book, covering basic measurements, comprises nine chapters and about 72 per cent of the text. The second part covers applications to magnetic measurements, electrical thermometry, electrical measurements in mechanics and acoustics, and electrical measurements in nuclear physics. It comprises four chapters and about 28 per cent of the text. Chapters five through nine cover null measurements at low frequencies, amplifiers, oscillators, measurements at radio frequencies, and measurements at high frequencies, and comprise about 40 per cent of the book. This is the area of primary interest to radio engi-

Much of the treatment of measurements circuits at radio frequencies is qualitative. and some of the rather fundamental instruments are only briefly mentioned. For example, the Q-meter receives one page and no analysis of the circuit is given, the susceptance variation method is not mentioned, nor are bridged-T and double-T circuits mentioned. In some places, the analytical work is good, as in the early part of the chapter on amplifiers, but at other places the book must be read with extreme caution. Some examples of statements which must be carefully examined are "...current generator, with zero internal impedance" (p. 118); "... the phase angle between the current and the voltage at resonance is 45°" (p. 178); and "These half-wave rectifying meters are identical in principle with the peak value meters . . . " (p. 180).

The second part of the book is quite valuable, because it shows a variety of uses of electrical measurements in the measurement of nonelectrical quantities. It is stimulating to the student to see this wide

diversity of applications.

On the whole, the book is a good one for students beginning their work in electrical measurements. It emphasizes the utility and value of electronic equipment in electrical measurement, without sacrificing the ground work in basic dc measurements.

G. B. HOADLEY North Carolina State College Raleigh, N. C.

#### Technical Aspects of Sound, Vol. Two, ed. by E. G. Richardson

Published (1957) by D. Van Nostrand Co., Inc., 257 Fourth Ave., N. Y. 10, N. Y. 406 pages +6 index pages +xii pages. 206 figures.  $9\frac{1}{4} \times 6\frac{1}{4}$ . \$11.75.

In this second volume of Technical Aspects of Sound, Professor Richardson, as editor, has maintained the high standards set in the first volume. The glittering list of contributors includes such names as Dean Erwin Meyer of Goettingen, Germany, and Harvey Hubbard of Langley Field, Virginia.

The book's four hundred pages are about equally divided between the three subjects: underwater sound, ultrasonics, and aircraft noise. Of particular interest is the section on underwater acoustics, since it includes a report on very recent work on air bubbles at Goettingen and a fairly complete discussion of the work on underwater absorbers which was carried on the U.S. and in Germany during the war. The sections on aircraft noise and underwater noise, though short, should also prove useful, since little has appeared on these subjects except in the classified literature

The section on propagation of sound in the sea is unfortunately rather short, as is the list of references. However, the discussion of long distance propagation of sound in the atmosphere includes material that is new and interesting.

Ultrasonic transducers are treated rather thoroughly as are the applications of ultrasonics, particularly the biological applications, a field which is much more active in Europe than in America. Chapter 5 brings to the English-literature a discussion of the extensive work of the past six or seven years on air bubbles by Dean Meyer and his several co-workers (Miss Exner and Messrs. Tamm, Skudrzyk, and Esche).

All in all, the book is easy to read and forms a valuable reference work for researchers in the physical acoustics field.

W. E. Коск Bendix Aviation Corp Ann Arbor, Mich

#### Statistical Methods in Quality Control by D. J. Cowden

Published (1957) by Prentice-Hall, Inc., 70 Fifth Ave., N. Y. 11, N. Y. 633 pages +15 index pages +74 pages of appendix+xxiv pages. Illus.  $9\frac{1}{4}\times6\frac{1}{2}$ . \$12.00.

Manufacturers of electronic equipment are realizing the need of quality control procedures for attaining predictable product, since predictability is a necessary ingredient of reliability.1 This book describes and illustrates many statistical techniques that may be used as aids in controlling the quality characteristics of a product as well as statistical sampling plans that may be used for judging whether the quality of a lot is acceptable or not.

The book is divided into three parts. The first ten chapters deal mainly with statistical methods that are applicable in general, such as certain types of distributions, estimators of the parameters of distributions, various tests of hypotheses concerning the values of parameters together with operating characteristics of the tests and an introduction to analysis of variance. Chapters 11 and 12 cover "tests of control," including the control chart.

Chapters 13-14, 16-17, 21-24, 26 and 28 in the second part, describe the use of tests of control for controlling production processes. Operating characteristic curves

<sup>1</sup> M. N. Torrey, "Quality control in electronics," Proc. IRE, vol. 44, pp. 1521–1530; November, 1956.

for several types of control charts for variables are constructed in Chapter 18 and used to evaluate different sampling frequencies in Chapter 19. The economics of control charts, Chapter 29, may be of particular interest to process control supervisors. Chapter 15 gives methods for setting specification limits by statistical methods and Chapter 27 outlines the procedure for fitting a straight line by least squares, which is used for sloping control lines.

The reviewer feels that more warning should be given about the increase in the risk of looking for trouble that does not exist when multiple tests of control are used on the same data as in Chapter 12. It is true that the effect of the multiplicity of tests is mentioned on page 173, but no allowance is made for it in the examples. Again, on pages 230-232, several "warning signals" are suggested for use with control charts, but the increased risk of looking for trouble that does not exist is not evaluated for the combination of tests.

The third part of the book, Chapters 30-40, is concerned mainly with "product control," or acceptance sampling plans. A few popular misconceptions are included in this part of the book, for example:

(1) The idea that a sampling plan his only one type of operating characteristic curve relating to lot quality and properly computed by means of the hypergeometric distribution. Actually there are two types of curves,2 one relating to "lot" quality, and the other relating to "product" quality assuming that the lot qualities are binomially distributed about the value of product quality. Most published operating characteristic curves, which are computed by means of the Poisson or binomial distributions, give the probability of acceptance for "product" of a given quality.

(2) The idea that the Army Service Forces Inspection Tables and later military tables, including Military Standard 105A, "minimize inspections before detailing" (pages 494

and 526).

(3) The idea that military acceptance sampling plans provide that "substantially all lots be satisfactory" (page 586). The specification of an AQL value in military plans does not describe protection to the consumer. The per cent defective in a substantial proportion of accepted lots may exceed the AQL value, since the AQL is the average level of lot quality that will be accepted most of the time by the sampling plan. The average level of per cent defective in submitted lots must be significantly larger than the AOL value before tightened inspection is called for.

This book was not written for the novice in either statistics or quality control. It is

<sup>2</sup> W. E. Deming, "Some Theory of Sampling." John Wiley and Sons, Inc., New York, N. Y.; 1950, Chapter 8.

a good reference book for one who has had statistical training and experience in the use of quality control techniques, since it includes many statistical techniques that could be useful in the quality control operation. The nearest competitor to this book is probably Quality Control and Industrial Statistics by Duncan.3 Professor Cowden's book includes more tests for control, or lack of it, while Professor Duncan's book includes more material on analysis of variance, regression and experimental design. The latter techniques can be useful in finding the assignable causes of lack of control.

On the whole, this is an above-average compilation of statistical techniques and tables. The quality control viewpoint is lacking as evidenced by the statement on

page 155:

"When testing whether or not control exists, the control chart should perhaps be considered mainly a diagnostic device, with final judgment based on other techniques."

The standard criteria for judging when control exists are based on the standard con-

trol chart. 4,5

Bell Tel. Labs. New York, N. Y.

<sup>3</sup> A. J. Duncan, "Quality Control and Industria, Statistics," Richard D. Irwin, Inc., Homewood, Ill.

Statistics," Richard D. Ifwlii, Inc., Hollico. 1955.

<sup>4</sup> W. A. Shewhart, "Statistical Method from the Viewpoint of Quality Control," Graduate School, Dept. of Agriculture, Washington, D. C., ed. by W. E. Deming; 1939.

<sup>8</sup> "American War Standard Control Chart Method of Controlling Quality During Production," Amer. Standards Assn., Inc., New York, N. Y., Z1.3-1942.

#### RECENT BOOKS

Alger, P. L., Mathematics for Science and Engineering. The trade edition based on Engineering Mathematics by C. P. Stein-Metz. McGraw-Hill Book Co., 330 W. 42 St., N. Y. 36, N. Y. \$6.95.

American Institute of Physics Handbook. Mc-Graw-Hill Book Co., 330 W. 42 St.,

N. Y. 36, N. Y. \$15.00.

Arguimbau, L. B., and Stuart, R. D., Frequency Modulation. John Wiley & Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. \$2.00.

Automatic Coding, Monograph No. 3. Proceedings of the symposium held Jan. 24-25, 1957 at The Franklin Institute, Philadelphia, Pa. Journal of The Franklin Institute, Philadelphia 3, Pa. \$3.00.

Burris-Meyer, Harold, and Goodfriend, Lewis. Acoustics for the Architect. Reinhold Publishing Corp., 430 Park Ave.,

N. Y. 22, N. Y. \$10.00. Douglas, Alan, The Electrical Production of Music, Philosophical Library, Inc., 15 E. 40 St., N. Y. 16, N. Y. \$12.00.

FM Stations Up-to-Date. Compiled by B. G. Cramer. Audiocraft Magazine, The Publishing House, Great Barrington, Mass.

Glozsary of Terms in Nuclear Science and Technology (ASA American Standard N 1.1-1957). American Society of Mechanical Éngineers, 29 W. 39 St., N. Y., N. Y. \$5.00.

Hausmann, Erich, and Slack, E. P., Physics, 4th ed. D. Van Nostrand Co., Inc., 257 Fourth Ave., N. Y. 10, N. Y. \$8.00.

Industrial Applications of Analog Computers: Proceedings of a Symposium for Management. April 10-11, 1956. Midwest Research Institute, 425 Volker Blvd., Kansas City 10, Mo. \$5.00.

Industrial Rectifying Tubes, Vol. XIII. Philips Technical Library book obtainable from Elsevier Press, Inc., 2330 Holcombe Blvd., Houston 25, Tex. \$2.15.

Kaufman, Milton, Radio Operator's License Q&A Manual, 6th ed. John F. Rider Publishers, Inc., 116 W. 14th St., N. Y. 11, N. Y. \$6.60.

Murray, R. L., Nuclear Reactor Physics. Prentice-Hall, Inc., 70 Fifth Ave., N. Y. 11. N. Y. \$10.00.

Nye, J. F., Physical Properties of Crystals. Oxford Univ. Press, 114 Fifth Ave., N. Y. 11, N. Y. \$8.00.

Proceedings of the Second RETMA Conference on Reliable Electrical Connections. Engineering Publishers, GPO Box 1151, N. Y. 1, N. Y. \$5.00.

Proceedings of the Second RETMA Symposium on Applied Reliability, Engineering Publishers, GPO Box 1151, N. Y. 1, N. Y. \$5.00.

Semiconductor Abstracts, Vol. III-1955 issue. Abstracts of literature on semiconducting and luminescent materials and their applications, compiled by Battelle Memorial Institute. John Wiley & Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. \$10.00.

Varner, W. W., Computing with Desk Calculators. Reinhart & Co., Inc., 232 Madison Ave., N. Y. 16, N. Y. \$2.00.

## First National Symposium on Engineering Writing & Speech

SHERATON-McAlpin Hotel, New York City, October 21-22

The IRE Professional Group on Engineering Writing and Speech will sponsor its first national symposium at the Sheraton-McAlpin Hotel in New York City, Oct. 21-22, 1957. The registration fee at the hotel is \$5.00. Members of the symposium committee include: D. J. McNamara, chairman; P. J. Lahey, program; H. B. Michaelson, finance; H. S. Renne, arrangements; T. E. Mount, registration; Lewis Winner, publicity; and E. M. McElwee, Group secretary.

#### Monday, October 21

#### Registration

Speech of welcome, D. J. McNamara, and symposium chairman.

#### Session I

Engineering Writing is Different, Lennox Grey, Teachers' College, Columbia Univ. Tricks of the Trade, J. D. Chapline, Technical Reports Dept., Philo Corp.

When You Write for the Air Force, Brig. Gen. H. A. Boushey, Office of Deputy Chief of Staff, Development, Dept. of the Air

#### LUNCHEON

Keynote address, J. R. Pierce, Bell

#### Session II

More Senses Make More Sense, C. N. Hoyler, RCA, Labs.

Panel discussion on "Should a Talk be Read from a Prepared Manuscript?" Participants: A. V. Loughren, Airborne Instruments Lab., and H. B. Michaelson, IBM Journal of Research and Development (pro): G. V. Eltgroth, Patent Council, Indus. Elec. Div., General Electric Co., and G. I. Robertson, Bell Tel. Labs. (con).

#### Reception and cocktail party

#### Session III

Scientific Staging, Lewis Winner, Bryan Davis Publishing Co.

Tuesday, October 22

Registration

#### Session iv

A Formula for Platform Poise, Rudy Norko, RCA.

Does It Have to be Slides?, Charles Tiene, Field Training Dept., Sperry Gyroscope Co.

Technical Films—A Luxury or a Necessity?, R. M. Murray, Engineering Services Dept., Hughes Aircraft Co.

#### LUNCHEON

A report of the formation, progress and plans of the PGEWS will be given.

#### Session v

Panel discussion on "What Magazine are You Writing for?" Moderator: Keith Henney, McGraw-Hill Publishing Co. Participants: Editorial staff members of Pro-CEEDINGS OF THE IRE, Electronics, Electronic Design, and Electrical Manufacture.

## Fourth Annual East Coast Conference on Aeronautical & Navigational Electronics

FIFTH REGIMENT ARMORY AND LORD BALTIMORE HOTEL, BALTIMORE, MD.

OCTOBER 28-30, 1957

The IRE Baltimore Section and the IRE Professional Group on Aeronautical and Navigational Electronics will again hold their annual East Coast Conference. Exhibits and an array of 42 technical papers, presented at the Fifth Regiment Armory, will elaborate on the theme, "Electronics in the Jet Air Age." A banquet and dance will be held at the Lord Baltimore Hotel on the evening of October 29. Capt. H. T. Orville will be the speaker and J. A. Hutcheson, toastmaster. Registration is \$1.00 for IRE members; \$3.00 for non-members.

Members of the conference steering committee are: A. A. Nims, chairman; J. A. Houston, vice-chairman; T. T. Eaton, finance; K. F. Molz, local arrangements; C. R. Maynard, exhibits; Harald Schutz, technical program; Joseph General, printing; and C. J. Knight, publicity.

#### Monday, October 28

#### NAVIGATION SYSTEMS

The Navigational Computer, P. J. Mc-Keown, Ford Instrument Co.

The Effects of Terrain Via Error on Doppler Navigator Accuracies, D. McColl and G. Burton, Raytheon Mfg. Co.

Air Route Surveillance Radar Facilities, B. McCaffrey, Raytheon Mfg. Co.

Transosonde System, H. Cubbage, U. S. Naval Research Lab.

Frontier Airline's Airways System, C. Longhart, Frontier Airlines.

Performance Analysis of Doppler Navigation Systems, W. R. Fried, WADC, USAF.

#### EQUIPMENT ANALYSIS

An Analytical Approach to the Vibration Design of Airborne Electronic Equipment, M. Gurtin, General Electric Co.

New Electronic and Metallurgical Ideas, Materials and Techniques, S. Freedman, Chemalioy Electronics Corp.

A Ram Air Cooling Study, R. Gammerman, Sylvania.

A Research Flight Simulator, J. Stoops and D. Entler, Jr., Westinghouse.

Procedures for Preliminary Analysis of Infra-Red Detection Systems, R. Laprade, R. Timm, and A. Schwartz, Westinghouse. Factors Affecting Tracking Performance When Using the Moving Aircraft Display, M. Mazina and A. Kahn, Westinghouse.

#### Tuesday, October 29

# MILITARY NAVIGATION TECHNIQUES

Sidelobe Suppression for ATC Beacon, C. Yule, NAS, Patuxent River.

A Hypothesis on the Use of Time, A.

Knight, WADC, USAF.

A Proposal for an Automatic Position Correction of a Dead Reckoning Navigational Computer Using Astrotracker Derived Celestial Data, C. Smykowski, Ford Instrument Co.

Automatic Thrust Control for Turbojet Aircraft, P. Story, Sperry Gyroscope Co.

Radar Ground Mapping Resolution, R. Timm and R. Laprade, Westinghouse.

Air/Ground Communication Problems, W. Vincent, A. Peterson and R. Leadabrand, Stanford Research Inst.

#### EQUIPMENT DESIGN

Liaison Engineering, J. Berkley, General Electric Co.

Automatology, A. Maynard, General Electric Co.

Prediction of Temperatures in Forced Convection-Cooled Equipment, L. Fried, General Electric Co.

A Forced Air Cooling System in Present Aircraft, T. Ellison, United Airlines.

Progress in Transistorized Audio Systems for Modern Airlines, J. Tewksbury, Bendix,

An Electronic System for Protecting Aircraft Fuel Tanks from Fire and Explosion, W. Bordewieck, Electronics Corp. of America.

#### STUDENT CONFERENCE

#### CIVIL NAVIGATION TECHNIQUES

An Automatic Guidance Computer Using Magnetic Amplifiers, J. Rector, Collins Radio Co.

Radio Compass Testing with Small Shielded Enclosures, A. Markham, Bendix Radio.

A New Navigation Package for the VHF Omni-Range System of Aircraft Navigation, A. Hemphill, Bendix Radio.

New Design Philosophies for Lightweight Civil Airborne Weather Radars, B. L. Cordry, Bendix Radio.

Interference Blanker Development, M. Newman, J. Stahmann and J. D. Robb, Lightning and Transients Research Inst.

#### Wednesday, October 30

## MICROWAVE COMPONENTS

Multiplex Ferrite Type Antenna Switch, H. C. Hanks, Jr., The Martin Co.

Ferrite Antenna Systems, H. Hanks, Jr. and J. Bruckert, The Martin Co.

Status in Systems Application of Available 8-9 Millimeter Wave Length Components, Magnetrons, TR and ATR Tubes, Crystal Mixers and Detectors, F. McCarthy, Sylvania.

A Novel Antenna Feed which Provides for any Remotely Selectable Polarization, Vertical, Horizontal Right or Left Hand, Circular Polarization without Moving Parts, T. Anderson, R. Hautzik, and E. Wantuch, Airtron, Inc.

A Packaged Medium-Power Traveling-Wave Amplifier Tube for Airborne Service, C. Novak and H. Wolkstein, RCA.

High-Power, Wide-Tuning-Range, X-Band Magnetrons Extremely Stable at Rates of Rise Above 200 KV/USEC, M. Ungar and J. Jacobs, RCA.

#### ELECTRONIC COMPONENTS

Ceramic Stacked-Mount Receiving Tubes, C. F. Douglass, Sylvania.

A Transistorized Pulse Generator, W. Donnell and J. Moffitt, Texas Instruments,

Applications of Direct View Storage Tubes to Air Traffic Control and Navigation, H. Gates, Farnsworth Electronics Co.

Improvement in Radar Presentation, K. Curtis and T. Kelly, Raytheon Mfg. Co. Operating Time Indicator, W. Erickson, Raytheon Mfg. Co.

Floated Rate-Integrating Gyro Performance—Criteria Optimization, J. W. Lower, Minneapolis-Honeywell Regulator Co.



# Third Aeronautical Communications Symposium

UTICA, N. Y., NOVEMBER 6, 7, 8, 1957

#### Wednesday, November 6

Registration at Hotel Utica.

#### SPECTRUM UTILIZATION

A Time Compressed Single Sideband System, John Mattern and M. I. Jacob, Westinghouse Electric Corp.

Comparison of Medulation Systems for Digital Transmission, R. Filipowsky and E. Scherer, Westinghouse Electric Corp.

Synchronous SSB for Aeronautical Communications, W. L. Firestone and Angus Macdonald, Motorola.

A Continuous Analysis Speech Bandwidth Compression System, T. E. Bayston and S. J. Campanella, Melpar, Inc.

An Experimental Realization of Spectrum Conservation, H. E. Haynes and D. T. Hoger, RCA.

#### Luncheon

#### Components and Equipment

Uniform Design Criteria for Airborne CN&I Equipment, H. Wamboldt, Wright

Air Development Ctr., and R. Trachtenberg, RCA.

An Airborne Receiver Technique for Obtaining Information from the Beam of a Ground Based Tracking Radar, R. J. McNair, Bell Aircraft Co.

Aircraft Electrical Systems for Transistor Electronic Equipment, J. A. Doremus, Aircraft Radio Corp.

Public Air-Ground Telephone Service Trial, L. M. Augustus, Michigan Bell Telephone Co.

Improved Utilization of Technical Man Hours, A. S. Brown, Stanford Research Inst.

#### Thursday, November 7

#### ANTENNAS AND PROPAGATION

Recent Advances in Pattern and Gain Measurement Techniques as Applied to Aircraft and Missile Antennas, K. C. Collins, Airborne Instrument Lab.

Tropospheric Scatter System Design Chart, L. P. Yeh, Westinghouse Electric Corp.

 $Space\ Diversification\ for\ Receiving\ Antennas\ in\ Scatter\ Communication\ Systems,$ 

G. B. Parrent, Jr., and M. J. Beran, AF Cambridge Research Ctr.

Effects of Selective Fading on AM Signals, W. D. Nupp, U. S. Naval Air Development

A Long Range VHF Meteor Burst Communications System, W. R. Vincent and A. M. Peterson, Stanford Research Inst.

## TECHNIQUES AND SYSTEMS

Quaternary Data Transmission System with Swinging Waveforms, R. Filipowsky, Westinghouse Electric Corp.

Choosing the Optimum Type of Modulation: A Comparison of Several Systems of Communication, G. J. Kelley, General Electric Co.

ABC—Air Block Control, H. K. Morgan, Bendix Aviation Corp.

Communication in Air Traffic Control, Robert Stuckelman, Wright Air Development Ctr.

Air Force Communications Equipment Looks into the Future, J. H. Vogelman, Rome Air Dev. Ctr.

## Third IRE Instrumentation Conference and Exhibit

BILTMORE HOTEL, ATLANTA, GEORGIA, NOVEMBER 11-13

## Monday, November 11 2:30 p.m.

#### DATA HANDLING SYSTEMS

Instrumentation for Static Test of C-130A Hercules, W. W. Hartsfield, Georgia Division, Lockheed Aircraft Corp.

In-Flight Recording for System Malfunction Detection, John Jamgochian and T. K. Speer, Georgia Division, Lockheed Aircraft Corp.

Dynamic Data System, B. J. Fister and C. A. Woodcock, General Electric Co., Aircraft Gas Turbine Div.

A Semi-Digital Process Simulator, M. Terao and K. Tamura, Electrotechnical Lab., Tokyo, Japan.

## Tuesday, November 12 9:30 a.m.

#### ANALOG-DIGITAL CONVERSION

Transistorized Digital to Analog Converter, W. D. Rowe, Motor and Control Division, Westinghouse Electric Corp.

A Novel Voltage Digitizer, Bernard Lippel, U.S. Army Signal Engineering Labs.

The Coding of Analog Lines for Transmission by Standard Teletype to Remote Displays, John Brown, Engineering Research Inst., Univ. of Mich.

Multi-Channel Digital Data Logging

System, Joseph Luongo, Federal Telecommunication Labs.

#### 2:30 p.m.

#### Data Reduction and Processing

Economical On-Line Data-Reduction System for Wind-Tunnel Force and Pressure Tests, M. Bain and M. Seamons, Jet Propulsion Lab., California Inst. of Technology.

An Automatic System for Handling Telemetered Data, C. B. McGuire, Boeing Airplane Co.

Automatic Recording and Reduction Facility for Project Vanguard, D. H. Gridley and W. B. Poland, Jr., Naval Research Lab., and C. E. Keith and R. S. Bowers, Radiation, Inc.

Data Handling for a Reliability Test Program, V. W. Walter and F. I. Bien, Inland Testing Labs.

#### Evening

Reception and buffet supper.

## Wednesday, November 13 9:30 a.m.

# Recording Devices and Techniques

A New Six Channel X-Y Recorder and Point Plotter, H. C. Craddock, ScientificAtlanta, Incorporated.

A High Speed Direct Writing Recorder, W. E. Harrison, Midwestern Instruments.

Design of Oscillographic Recorders for Efficient Use, V. E. Payne, U.S. Naval Ordnance Unit, Key West, Fla.

Techniques in Evaluating Instrumentation Type Magnetic Recording Tape, T. O. Moore, Orradio Industries, Inc.

Electronic Techniques in Liquid Level Measurement, T. L. Greenwood, Redstone Arsenal.

#### 2:30 p.m.

# Instrumentation Methods And Principles

Some Fundamental Topics in Analog-Digital Interconversion, Bernard Lippel, U.S. Army Signal Engineering Labs.

General Design Considerations for Man-Machine Systems, J. C. Groce, Federal Telecommunication Labs.

System Study Through Frequency Contour Mapping, J. H. Fisher and R. S. Gaylord, The Ramo-Wooldridge Corp.

Definition and Synthesis of Optimum Smoothing Processes in Filter Terms, E. M. Boughton, 1st Lt., USAF, Holloman AFB.

The Uncertainty of Ideal Measurement Systems, J. B. Chatterton, Sperry Gyroscope Co.

## Radio Fall Meeting

NOVEMBER 11, 12, 13, 1957, KING EDWARD HOTEL, TORONTO, CANADA

The meeting is sponsored by the Engineering Department of the Electronic Industries Association with the active participation of the IRE Professional Groups. Advance registration will be available at \$4.00 upon request to the EIA Engineering Department, Rm. 650, 11 W. 42 St., New York 36, N. Y. All checks should be made out to EIA Engineering Department. Registration at the door will be \$5.00. All tickets for the Radio Fall Meeting dinner will be available for sale at the door only.

#### Monday, November 11

#### EIA ENGINEERING DEPARTMENT

M. A. Acheson, presiding.

Television in Ten Languages, C. J. Hirsch,
Hazeltine Corp.

International Component Standardization, Leon Podolsky, Sprague Electric Co.

EIA Activities in Automation, J. J. Harrington, Arthur D. Little, Inc.

#### Quality Improvement and Reliability

J. R. Steen, presiding.

Progress in TV Receiver Reliability, E. H. Boden, Sylvania Electric Products, Inc.

Reliability Control Based on Multiple Sequential Feedback, C. M. Ryerson, RCA.

Purchasing Reliability, E. J. Breiding, IBM Corp.

Establishing a Practical Routine for Measuring TV and Radio Tube Quality in the Customer's Plant, D. M. Palamountain, Raytheon Manufacturing Co.

## Stag Party Tuesday, November 12

RADIO AND TELEVISION

J. F. McAllister, presiding.

Development of the 12-Volt Plate-Voltage Hybrid Automobile Radio Receivers—AM, Signal-Seeker and FM, C. C. Hsu, Bendix Radio Div.

Local Oscillator Radiation from Television and FM Sets, W. G. Peterson, Warwick Manufacturing Corp.

Techniques Involved in Meeting FCC Radiation Requirements at UHF, John Bell, Zenith Radio Corp.

Design Consideration of a Development UHF Tuner Using an RF Amplifier, J. B. Quirk, General Electric Co.

All-Transistor FM Radio Receiver, H. V. Stewart, Texas Instrument Co.

#### RADIO AND TELEVISION

Preben Gomard, presiding.

Minimizing the Effect of Cut-Off in TV Vertical Oscillators, S. F. Love, Radio Valve Co., Ltd.

Automatic Fine Tuning Circuitry in TV Receivers, K. W. Farr and L. J. Sienkiewicz, Westinghouse Electric Corp.

Vacuum Tube Requirements in Vertical-Deflection Circuits, K. W. Angel, RCA.

The Property of TV Sync Separator Without and With Interference Pulses in the Composite Signal, Eduaid Luedicke, RCA Victor Co., Ltd.

Analysis and Synthesis of Magnetic Fieldin Yokes Using Rotating Probes, H. S. Vasilevskis, Philco Corp.

#### Cocktail Party

#### Radio Fall Meeting Dinner

Toastmaster: J. T. Henderson, President,

Speaker: To be announced.

#### Wednesday, November 13

#### ELECTRON DEVICES I

J. T. Cimorelli, presiding.

Design and Development of the RCA-21CYP22 21 Glass Color Picture Tube, C. P. Smith, A. M. Morrell, R. C. Demmy, RCA.

Application of the RCA 21CYP22 Round Glass Color Picture Tube, H. N. Hillegass, R. W. Hagmann, D. J. Ransom, RCA.

Earth's Field Effects in Shadowmask Color Tubes, G. A. Burdick, Sr., Sylvania Electric Products, Inc.

Tetrode Driver Tube for Hybrid Auto Sets, Joseph Gaziano, Raytheon Manufacturing Co.

Typical Germanium Power Transistor Data and Typical Circuit Applications, W. C. Caldwell and L. L. Lehner, Bendix Aviation Corp.

#### ELECTRON DEVICES

H. L. Owens, presiding.

Present Status of Transistor Receiver Design Procedures, W. H. Ryer and W. E. Sheehan, Raytheon Manufacturing Co.

Design Considerations for Tfansistor Portable Reflex Receivers, R. V. Fournier, RCA.

A Broadcast Receiver Using Diffused Meltback Transistors, Erich Gottlieb, General Electric Co.

Silicon TV Rectifiers, H. W. Henkels and Victor Sils, Westinghouse Electric Corp.

Effect of Transient Voltage on Junction Transistors, H. C. Lin and W. F. Jordan, Jr., CBS-Hytron.

Parameter Variation Results Affecting Multi-Stable Circuits, W. J. Maloney, General Electric Co.

## Abstracts of IRE Transactions\_\_\_

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	Group Members	IRE Members	Non- Members*
Circuit Theory	Vol. CT-4, No. 2	\$0.70	\$1.05	\$2.10
Reliability & Quality Control	PGRQC-11	1.35	2.00	4.05

<sup>\*</sup> Public libraries and colleges may purchase copies at IRE Member rates.

#### Circuit Theory

Vol. CT-4, No. 2, June, 1957

Abstracts of Papers in This Issue (p. 28)
Applied Circuit Theory—W. N. Tuttle (p.

Design of Unsymmetrical Band-Pass Filters
—R. F. Baum

The paper presents a new approach to the synthesis of band-pass filters, in particular of filters with electrical characteristics which are not symmetrical with respect to their center frequency when plotted on an arithmetic frequency scale.

The synthesis proceeds in three steps: approximation, representation by means of fic-

titious network elements in the low-pass domain, and subsequent low-pass, band-pass transformation.

The approximation process leads to network functions defined by polynomials containing complex coefficients. It is shown that these functions can be handled with available synthesis procedures, if suitable modifications are made. This technique is based upon the properties of quasi-Hurwitz polynomials, treated in the appendix. These procedures then lead to a network representation in the low-pass domain, which includes two fictitious network elements, namely, constant positive or negative imaginary quantities. After a low-pass, band-pass transformation has been applied the network becomes physically realizable.

It is shown that unsymmetrical lossless networks can be developed into canonic forms in the low-pass domain.

A practical example is given.

Analysis and Synthesis of Delay Line Periodic Filters-H. Urkowitz (p. 41)

A periodic filter has a frequency characteristic which is periodic. Such filters can be constructed using delay lines where the delay of each line is the reciprocal of the basic frequency period. The network function of the periodic filter is characterized by the presence of the factors of the form  $e^{np\tau}$ , where n is a positive or negative integer,  $\tau$  is the delay of each delay line, and p is the complex frequency variable. Analysis and synthesis are simplified by use of the z transform which has been used with much success in the study of sampled data systems. A transformation of the filter network function is made by substituting z for  $e^{p\tau}$ . This substitution transforms the imaginary axis of the p plane into the central unit circle in the z plane.

The properties of the periodic filter are now characterized by the poles and zeros of the z-plane transform. A rational method is

presented for synthesizing any z-plane transform expressed as a rational fraction. Finally, the z-transform concept is used to analyze the behavior of periodic filters with pulsed inputs.

Reviews of Current Literature-Abstracts of Articles on Circuit Theory-Outline of Generalized Filter Theory-E. Henze (in German), (p. 54)

Neutralization of the Selective Transistor Amplifier-G. Meyer-Brotz (in German). (p.

Admittance Matrix of Active and Passive Networks—H. Pecher (in German). (p. 54) Gyrators and Non-Reciprocal Systems-

M. Prudhon (in French). (p. 54)

A Low-Pass/Band-Pass Frequency Transformation—K. Irani (in English). (p. 54)

On the Coupling Between Two Cavities-R. N. Gould and A. Cunliffe (in English). (p.

Nonlinear Oscillators with Constant Time Delay-W. J. Cunningham (in English). (p. 55)

Evaluation and Design of Dissipative Composite Wave Filters-J. Scholten (in English). (p. 55)

Frequency Conversion with Positive Nonlinear Resistors-C. H. Page (in English). (p.

Some Theorems on the Decomposition of the Operational Impedance of a Two-Terminal Electric Network-L. Lunelli (in Italian). (p.

Correspondence (p. 55) PGCT News (p. 56)

#### Reliability & Quality Control

PGRQC-11, August, 1957

(Papers Presented at the Third National Symposium, Washington, D. C., Jan. 14-15,

Progress in Reliability of Military Electronic Equipment During 1956-J. M. Bridges

The Military Reliable Tube Program-

K. C. Harding (p. 8)

Evaluation of Transistor Life Data—J. D. Johnson and B. VanSwearingen (p. 15)

The purpose of evaluating transistor life data is to make possible proper application, specification and design of transistors. There are many methods of testing and analyzing life characteristics. These methods are reviewed and discussed here from the standpoint of the user, with emphasis on a particular statistical approach.

Components are initially evaluated at different temperatures to determine such general characteristics as current gain and leakage currents in the collector and emittor cutoff region. Samples are also submitted to mechanical and environmental tests. Life tests are conducted at various temperature and power levels. As a control feature, shelf life tests are usually performed simultaneously. Data collected from life tests are recorded on punched cards. Each card contains all the data for a given transistor at a particular time during the life test. This information is used as the input for an electronic calculator by means of which statistical summaries can be computed. The use of calculators accelerates the evaluation period and therefore allows more data to be analyzed efficiently. This method permits either individual or group evaluation procedures. Results are presented on curves and charts.

On the Measurement of Component Reliability—I, K. Munson (p. 27)
In-Process Controls to Maximize Capacitor

Reliability—H. S. Herrick (p. 34)

Military Weapon Systems Complex and the Professor Factor—D. E. Noble (p. 54)

Method for the Determination of Reliability K. E. Portz and H. R. Smith (p. 65)

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#### ACOUSTICS AND AUDIO FREQUENCIES 534.2-14

On Wave Propagation in a Randon Inhomogeneous Medium-D. S. Potter and S. R. Murphy. (J. Acoust. Soc. Amer., vol. 29, pp. 197-198; February, 1957.) A derivation of the coefficient of variation of intensity.

Double Relaxation Effects-R. T. Bever. (J. Acoust. Soc. Amer., vol. 29, pp. 243-248; February, 1957.) Expressions are derived for the velocity of ultrasonic waves in fluid media and the excess absorption coefficient assuming two relaxation processes. The results are discussed for several special cases.

#### 534.2:621.395.623.52

Analysis of the Wave Parameters of the Exponential Horn-J. Kacprowski. (Arch. Elektrotech., vol. 5, pp. 719-755; 1956. English summary, pp. 757-758.) The wave parameters of an exponential horn of finite length are evaluated on the basis of the general theory of four-terminal networks using matrix algebraic methods, and the results obtained are extrapolated for horns of infinite length. The concept of wave impedance of a horn is discussed. The transformation properties of the horn are analyzed.

On Scattering and Reflection of Sound by Rough Surfaces-V. Twersky. (J. Acoust. Soc. Amer., vol. 29, pp. 209-225; February, 1957.) A detailed analysis which extends the original work of Rayleigh and the previous work of the author (e.g., J. Appl. Phys., vol. 24, pp. 659-660; May, 1953.)

The Index to the Abstracts and References published in the PROC. IRE from February, 1956 through January, 1957 is published by the PROC. IRE, May, 1957, Part II. It is also published by Electronic and Radio Engineer, incorporating Wireless Engineer, and included in the March, 1957 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers'

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#### 534.24

On the Reflection of Sound at an Interface of Relative Motion-J. W. Miles. (J. Acoust. Soc. Amer., vol. 29, pp. 226-228; February, 1957.) An analysis of reflection of a plane wave at an interface between two perfect fluids. The errors and limitations of previous work are discussed.

#### 534.52

Scattering of Sound by Sound-P. J. Westervelt. (J. Acoust. Soc. Amer., vol. 29, pp. 199-203; February, 1957.) The effects of interaction are calculated by means of a scattering

#### 534.6:534.241

The Development of "Echo-Parameter" Measuring Equipment-H. Niese. (Nachr-Tech., vol. 6, pp. 545-552; December, 1956.) This parameter was defined earlier (670 of 1957) as the ratio of disturbing sound energy to total sound energy (useful+disturbing) received at the point of observation. A source of sound pulses (see 2324 of 1957) and special microphone are used to produce automatically an echo oscillogram from which the parameter can be derived.

Note on the Design of "Terminal-Analogue" Speech Synthesizers—J. L. Flanagan. Acoust. Soc. Amer., vol. 29, pp. 306-310; February, 1957.) The synthesis of vowel sounds by lumped-constant electrical networks having transfer functions similar to the transmission properties of the vocal tract is considered.

#### 534.86:534.76

Influence of Noise upon the Equivalence of Intensity Differences and Small Time Delays in Two-Loudspeaker Systems-D. M. Leakey and E. C. Cherry. (J. Acoust. Soc. Amer., vol. 29, pp. 284-286; February, 1957.) The effect is measured with speech and wide-band noise.

#### 621.395.613.386

Ear-Insert Microphone-R. D. Black. (J. Acoust. Soc. Amer., vol. 29, pp. 260-264; February, 1957.) Results are presented of an investigation of factors which make possible the use of a microphone in the ear to pick up the voice of the wearer.

Piezoelectric Ceramic "Bimetal" Strips used as Electroacoustic Transducers: Microphones-J. Peyssou. (Ann. Radioélect., vol. 12, pp. 33-44; January, 1957.) A formula is derived for the emf generated by a cantilever formed by a twin strip of piezoelectric materials which is subjected to a bending moment. This

effect is utilized in a form of microphone and various means of modifying its impedance are discussed. A circular "biceramic" diaphragm is designed, but the rectangular strip used as cantilever with its free end acting on the metal diaphragm of a microphone is a more efficient transducer.

#### 621.395.614:546.289

Piezoresistive Semiconductor Microphone -F. P. Burns. (J. Acoust. Soc. Amer., vol. 29, pp. 248-253; February, 1957.) Design and constructional data are given for a germanium rod microphone. Performance is compared with that of a standard carbon button transmitter.

#### 621.395.616:534.612.2

Condenser Microphones for Measurement of High Sound Pressures-J. K. Hilliard and W. T. Fiala. (J. Acoust. Soc. Amer., vol. 29, pp. 254-260; February, 1957.)

The Characteristics of Magnetic Recording Heads and Tapes—H. P. Spring. (J. Brit. IRE, vol. 17, pp. 217–233; April, 1957.) The fundamental principles, operating conditions, and limitations are discussed. Some novel designs are described and the effect of head and tape wear on frequency response is measured.

#### ANTENNAS AND TRANSMISSION LINES 621.372.2:621.385.16

The Attenuation of the Helical Wire Line-G. Schiefer. (Arch. elekt. Übertragung, vol. 11, pp. 35-40; January, 1957.) The propagation of an infinite number of partial modes along an inhomogeneous delay line based on Sensiper's model (1247 of 1955) is considered so as to determine the attenuation constant of the helical line. Some of the results calculated differ considerably from previous solutions obtained by considering the fundamental mode only. Diagrams are given for finding the attenuation constant as a function of line dimensions, wavelength, and wire conductivity.

#### 621.372.2.029.6

The Mode Conversion Phenomena of Laminated Transmission Lines and Their Influence on the Transmission by Single or Coupled Sections—H. E. Martin. (Arch. elekt. Übertragung, vol. 11, pp. 7-16 and 81-96; January/February, 1957.) The problem is considered of coupling power from coaxial into laminated lines, and vice versa, using graded potentials to reduce mode conversion losses [see also 328] of 1955 (Kaden and Martin)]. The influence of the dimensions and the transitions is investigated and methods of measuring transmission characteristics are discussed. Approximate formulas are derived for transmission coefficients of an arrangement consisting of several seriesconnected laminated line sections.

621.372.21:621.315.213

2668

Theory of the Microstrip-T. T. Wu. (J. Appl. Phys., vol. 28, pp. 299-302; March. 1957.) A discussion of the current distribution of the lowest mode of a transmission line consisting of a thin metallic strip pasted on the dielectric coating of a second and extensive conductor.

621.372.22

Computation of the Impedances of Nonuniform Lines by a Direct Method-L. A. Pipes. (Commun. & Electronics, no. 27, pp. 551-554; November, 1956.) The impedances are computed by solving first-order nonlinear differential equations of the Riccati type. Special cases which include the uniform line, the Bessel line, and the Heaviside-Bessel line are discussed.

621.372.8:538.566.2

Orthogonality Relation for Gyrotropic Waveguides—L. R. Walker. (J. Appl. Phys., vol. 28, p. 377; March, 1957.) A generalization of a simpler theorem which is applicable to guides partially filled with ferrite or plasma.

621.372.8:621.317.352

Equipment for Measuring Attenuation of the Holl Wave in Short Sections of Waveguides by the Cavity Resonance Method—V. M. Vakhnin and T. F. Kolodina. (Radiotekhnika i Elektronika, vol. 1, pp. 1485-1491; December, 1956.) A method is described of measuring the attentuation in cylindrical waveguides, with diameters of 50 mm, at a wavelength of 3.2 cm. The method is based on a comparison of the resonance curve of the measured volume with the frequency characteristic of an integrating RC circuit. Random errors are less that 1 per cent. The equipment is suitable for the determination of the influence of various factors, such as surface treatment, on the attenuation. A section drawing and photograph of the resonator are shown and a block diagram of the Q meter is given.

621.396.674.1 2672

Impedance of Thin-Wire Loop Antennas-J. E. Storer. (Commun. & Electronics, no. 27, pp. 606-619; November, 1956.) rigorous Fourier-series solution is modified to avoid convergence difficulties. Calculated loop impedances for various wire gauges and antenna circumferences up to 2½ λ are tabulated, and curves for the computation of field patterns and current distribution are given.

621.396.677 2673

A Limiting Case in the Design of an Excited-Reflector Antenna—V. A. Krishnaswamy. (J. Inst. Telecommun. Eng., India, vol. 3, pp. 38-42; December, 1956.) A discussion of a limitation in the use of an excited reflector in a two-element broadside array.

621.396.677:621.396.933.2

D.F. Antenna System for Decimetre Wavelengths-C. Clarke. (Electronic Radio Eng., vol. 34, pp. 238-245; July, 1957.) The development and performance of two antenna systems, for vertically and horizontally polarized waves, respectively, are described. They are designed to work with a twin-channel cr-tube instrument having an azimuthal coverage limited to a selected 90° sector.

621.396.677.3:523.16:523.72

Interferometer for the Study of Localized Solar Sources of Centimetre Waves-Alon, Kundu, and Steinberg. (See 2733.)

621.396.677.833:523.16 2676 A New Form for a Giant Radio Telescope-

Head. (See 2736.)

621.396.677.833.012.12

A Method of Measuring the Directivity Characteristics of Radiotelescopes with High Resolving Power—N. A. Esepkina. (C.R. Acad. Sci. U.R.S.S., vol. 113, pp. 94–96; March 1, 1957. In Russian.) Equations given relate the directivity characteristic of a system comprising a primary radiator at the focus of a parabolic mirror to that of a system in which the radiator is displaced from the focus along the axis of the mirror. Results are given of an experimental verification on a system comprising a primary radiator of 3-cm-λ radiation and a parabolic mirror with aperture 150 cm and focal length 50 cm; directivity curves obtained from measurements at a distance of 150 m with the primary radiator at the focus agree closely with those obtained at 13 m with the primary radiator displaced by 3 cm.

621.396.677.833.2:621.396.96 2678 A New Type of Surveillance [radar] Antenna: a Paraboloid Illuminated by a

Slotted Waveguide-L. Thourel. (Ann. Radioélect., vol. 12, pp. 3-13; January, 1957.) The production of a radiation pattern of given shape by means of a paraboloidal reflector illuminated by an equiphase linear source, such as a slotted waveguide, is described. Calculation and construction methods are indicated. The gain obtained with a reflector 1.8 m high is comparable to that of a double curvature reflector of 2.5-m

#### AUTOMATIC COMPUTERS

681.142

2677

The Principles of Universal Numerical Computers-F. H. Raymond. (Onde élect., vol. 36, pp. 838-841; October, 1956, and vol. 37, pp. 68-78; January, 1957.) Continuation and conclusion of paper included in the Electronic Computer issue of the journal (see 997 of 1957).

681.142

Designing for Reliability-N. H. Taylor. (Proc. IRE, vol. 45, pp. 811-822; June, 1957.) A discussion of reliability as applied to digital computer technology. The choice of components, their application, and considerations of design are discussed in detail. The design of a high-speed, vacuum-tube flip-flop is considered as a practical example.

681.142

Punched-Card Transcriber for Automatic Computers—(Tech. News Bull. Nat. Bur. Stand., vol. 41, pp. 38-39; March, 1957.) The unit described is intended for use with the SEAC computer (see 385 of 1951).

2682

Magnetic Data Recording Theory: Head Design-A. S. Hoagland. (Commun. & Electronics, no. 27, pp. 506-512; November, 1956.) The relation of the read-back waveform to bit density is examined and basic theoretical expressions are derived. The design of a recording head for magnetic disks is discussed with the aid of experimental results.

681.142

Number Systems for Computers-I. J. Gabelman. (Electronic Ind. Tele-Tech. vol. 15, pp. 32-33, 118; December, 1956.) Decimal, binary, octal, bi-quinary, coded-decimal, and excess-three systems are considered.

The Generation of Random Numbers on Automatic Computers-S. von Hoerner. (Z. angew. Math. Phys., vol. 8, pp. 26-52; January 25, 1957.) Some mathematical methods are summarized and a new one, which avoids the formation of stable cycles and degeneration, is discussed. The theory of random-number generation using  $\gamma$  radiation is confirmed by means of the experimental arrangement described.

681.142:621.374.5.001.4

Locating "Open Heaters" in Computer Circuitry—R. L. Ives. (Electronic Ind. Tele-Tech., vol. 15, pp. 46-47, 102; December, 1956.)

681.142:621.374.32:621.314.7

2686

Computer Switching with Micro-alloy Transistors—J. B. Angell and M. M. Fortini. (Electronic Ind. Tele-Tech. vol. 15, pp. 38-39, 126; December, 1956.) Transistor characteristics are discussed in relation to flip-flop cir-

## CIRCUITS AND CIRCUIT ELEMENTS

Contribution on the Calculation of the Total Impedance of Parallel-Connected Impedances —F. R. Belot. (*Rev. gén. Élect.*, vol. 65, pp. 675–676; December, 1956.) Outline of a slightly modified version of Boesch's method (991 of 1956) and description of a purely graphical method for rapidly obtaining results of adequate accuracy.

621.3.049

High-Temperature Subassembly Design-R. B. Kieburtz. (Electronics, vol. 30, pp. 158-161; May 1, 1957.) A component-by-component survey of the problems involved and progress to date in achieving reliable operation at 500°C.

621.314.26

Frequency Conversion by means of a Special Electronic Device-V. P. Tychinski. (Radiotekhnika i Elektronika, vol. 1, pp. 1525-1526; December, 1956.) The changes of frequency produced by the application of a modulating voltage to the helix of a travelingwave tube [1808 of 1956 (Beck)] are discussed with reference to the application of this phenomenon in a frequency changing device.

2690

Theory of Inhomogeneous Transmission Lines-S. I. Orlov. (Zh. Tekh. Fiz., vol. 26, pp. 2361-2372; October, 1956.) An expression is derived for the coefficient of reflection at the input of an arbitrary inhomogeneous line connected to an arbitrary complex impedance. For small inhomogeneities in a lossless line the problem of determining the law of change of the wave impedance along the line, is approximately solved, given the reflection coefficients at the input and output of the line as functions of frequency. The analysis is based on the classical theory of inhomogeneous transmission

621.372.412 2691

Crystal-Controlled Oscillators-G. Becker. (Arch. elekt. Übertragung, vol. 11, pp. 41-47; January, 1957.) The characteristics of a number of oscillator circuits are discussed with reference to the criteria for the basic series-resonance and parallel-resonance types (see also 2048 of 1957).

621.372.5/.6 Topological Analysis of Linear Nonrecipro-

cal Networks-S. J. Mason. (Proc. IRE, vol. 45, pp. 829-838; June, 1957.)

621,372,5

Time and Frequency Characteristics of Linear Pulse Systems with Variable Parameters-G. P. Tartakovski. (Radiotekhnika i Elektronika, vol. 1, pp. 1463-1473; December, 1956.) Theoretical paper. The application of the concepts introduced is illustrated by a discussion of a RC circuit under the influence of a pulsed fm signal.

621.372.5:512.9

Circuit Analysis by Normalization-J. J. Hupert. (Electronic Eng., vol. 29, pp. 226-230; May, 1957.) A method of network analysis based on a normalization procedure similar to that used in the concept of the normalized resonance curve.

resonance curve.

621.372.6

2695

The Interconnection of Two Multipoles—W. Ruppel. (Arch. elekt. Übertragung, vol. 11, pp. 33-34; January, 1957.) A method is described of determining the scattering matrix of a 2n-terminal network consisting of two parts, if the matrices of the partial 2n-terminal networks are known.

621.373+621.375.9]:538.561.029.6 2696 Negative-Temperature Reservoir Amplifiers—Motz. (See 2726.)

621.373:621.396.822

Noise in Nonlinear Oscillators—M. A. Garstens. (J. Appl. Phys., vol. 28, pp. 352–356; March, 1957.) An approximate solution is obtained of a nonhomogeneous nonlinear differential equation of van der Pol type for a noise driven oscillator.

621.373.029.42

A Two-Phase Low-Frequency Oscillator:
Part 2—E. F. Good. (*Electronic Eng.*, vol. 29, pp. 210-213; May, 1957.) Part 1: 2372 of 1957.

Oscillators Unaffected by Load Impedance —F. Frisch and W. Herzog. (Nachrichtentech. Z., vol. 10, pp. 35–38; January, 1957.) Oscillator circuits with frequency and amplitude independent of load impedance are examined (see also 1367 of 1957). Measurements on two experimental 100-kc oscillator circuits show that frequency changes are of the order of 0.1 per cent and do not exceed 0.35 per cent irrespective of load impedance.

621.373.421 2700
Investigations of the Nyquist Effect—H.
Barkhausen and E. G. Woschni. (Hochfreq.
und Elektroakust., vol. 64, pp. 180–184; May,
1956.) Results of theoretical and experimental
investigations on a Hartley-type oscillator are
discussed.

621.373.421.11 2701 Variable-Frequency Generator of High Frequency Stability—S. Ryżko, R. Nowak, and J. Fórmaniak. (Arch. Elektrotech., vol. 5, pp. 759–766; 1956. English summary, p. 767.) An oscillator for the 1.5–3-mc frequency range is designed on the basis of Groszkowski's analysis (2337 of 1956) of the Gouriet-Clapp oscillator (1627 of 1950 and 3170 of 1954). The temperature coefficient of frequency is  $+4\times10^{-6}$ /°C, and short-period frequency fluctuations are less than  $\pm3\times10^{-6}$ .

621.373.421.14:621.372.413

Excitation of Oscillations in a High Q-Cavity Resonator by an Oscillator—A. P. Fedotov and B. K. Shembel'. (Radiotekhnika i Elektronika, vol. 1, pp. 1474–1477; December, 1956.) A calculation of an antiparasitic ('quenching') resistor in the line connecting the oscillator with the high-Q cavity resonator is presented.

621.373.444.1 2703 A Millimicrosecond Timebase—M. W. Jervis and R. T. Taylor (*Electronic Eng.*, vol. 29, pp. 218–219; May, 1957.) Circuit and performance of a hard-tube timebase producing a rate of change of voltage of  $5 \times 10^{\prime\prime} \text{v/sec}$  are described.

621.373.52
Transistor Relaxation Oscillations—F. J. Hyde and R. W. Smith. (*Electronic Eng.*, vol. 29, pp. 234–236; May, 1957.) The continuous relaxation oscillations occurring in a point-contact transistor circuit using a cr combination in shunt with the emitter input are studied

as functions of emitter bias and ambient temperature. A method of temperature compensation is described.

621.373.52:621.373.431.1 2705

Multivibrator with Point-Contact Semiconductor Triode—K. S. Rzhevkin and M. A. Abdyukhanov. (Radiotekhnika i Elektronika, vol. 1, pp. 1478–1484; December, 1956.) The operation of a transistor multivibrator is briefly analyzed and design formulas are given. Calculated and experimental values are tabulated for comparison.

621.374.3:621.314.7

Transistorized Low-Level Chopper Circuits

—R. B. Hurley. (Electronic Ind. Tele-Tech., vol. 15, pp. 42–43, 112; December, 1956.) Improved performance is obtained by the use of stabilizing and compensating resistances in collector and emitter circuits.

621.374.32:621.316.8.012.7 2707 Tolerance Limit of Resistors in Binary Scaling Units—B. M. Banerjee and S. Choudhury. (*Electronic Eng.*, vol. 29, pp. 237–241; May, 1957.) An experimental investigation shows that limits of  $\pm 20$  per cent are permissible if optimum values are chosen for the cathode resistor.

621.374.33

Linear Gate of 200 Millimicrosecond Duration—E. L. Garwin and A. S. Penfold. (Rev. Sci. Instr., vol. 28, pp. 116–119; February, 1957.) The circuit gives an inverted output with a gain very close to unity and has a linearity within 1 per cent for pulses in the range 1 to 70 v.

621.375.2 2709 Operation of a Valve in a Grounded-Grid Circuit—A. Smoliński. (Arch. Elektrotech., vol. 5, pp. 621-642; 1956. English summary, pp. 643-644.) Theoretical analysis.

621.375.3 2710
Magnetic-Amplifier Control of Switching Transistors—H. W. Collins. (Commun. & Electronics, no. 27, pp. 585–589; November, 1956.) The circuits described use a magnetic amplifier to control the average output power of switching transistors by pulse-width modulation combined with high-gain amplification.

#### GENERAL PHYSICS

535.13:537.122

Particle Aspect of the Electromagnetic Field Equations—R. H. Good, Jr. (*Phys. Rev.*, vol. 105, pp. 1914–1919; March 15, 1957.) Maxwell's theory of the electromagnetic field in vacuum can be stated in a form closely similar to Dirac's theory of the electron.

Fluctuations and Irreversible Thermodynamics—L. Tisza and I. Manning. (*Phys. Rev.*, vol. 105, pp. 1695–1705; March 15, 1957.) The theory of kinetic (time-dependent) fluctuation problems is developed on the basis of the kinetic analog of the Boltzmann-Einstein principle given by Onsager and Machlup (*ibid.*, vol. 91, pp. 1505–1515; September 15, 1953.)

537.122:539.15:621.315.61

Effective Mass Approximation for Excitons

—G. Dresselhaus. (*Phys. Chem. Solids*, vol. 1, pp. 14–22; September/October, 1956.)

Contact Electrification across Metal/Dielectric and Dielectric/Dielectric Interfaces—G. S. Rose and S. G. Ward. (Brit. J. Appl. Phys. vol. 8, pp. 121–126; March, 1957.) The transfer of charge, across the interface produced when spherical and planar specimens are pressed into contact, has been measured.

537.31 2715

A Idielectric Cylinder in the Rield of a Point

A [dielectric] Cylinder in the Field of a Point Source of Electric Current—B. P. D'yakonov. (Bull. Acad. Sci. U.R.S.S., sér. géophys., no. 1, pp. 116–121; January, 1957. In Russian.) Theoretical calculation of the effect of an infinitely long cylinder of conducting dielectric embedded in a medium containing the point source of current.

Electron and Lattice Conduction in Metals
—I. I. Hanna and E. H. Sondheimer. (*Proc. Roy. Soc. A*, vol. 239, pp. 247–266; February 26, 1957.) Simple expressions are derived for the conduction magnitudes which are exact at high and low temperatures and are assumed to be approximately valid for all temperatures.

537.312.62 2717 Superconductivity—(Wireless World, vol. 63, pp. 326–330; July, 1957.) A discussion of the principles and applications.

537.52:621.317.382.029.63/.64 2718 Effect of Microwave Signals Incident upon Different Regions of a D.C. Hydrogen Glow Discharge—Udelson. (See 2866.)

On the Measurement of Ionic Densities in Electric Discharges at High Frequency by means of Perforated Probes—A. Pozwolski. (C.R. Acad. Sci., Paris, vol. 244, pp. 1744–1746; March 25, 1957.) Measurements on hydrogen and argon discharges show negative and positive currents rising to a maximum at a pressure of about 0.05 mm Hg and dying away asymptotically as the pressure rises.

537.533.72:621.385.833
Graphical-Analytical Construction of Space
Trajectories of Charged Particles in Electrostatic Fields by the Method of Radii of Curvature—N. I. Shtepa. (Zh. Tekh. Fiz., vol. 26, pp. 2281–2286; October, 1956.)

Reverse Current in Apparatus of the Spherical-Capacitor Type—M. Ya. Mandel'shtam. (Zh. Tekh. Fiz. vol. 26, pp. 2234–2242; October, 1956.) In investigations of the energy distribution of secondary electrons by bombardment of a target in a spherical collector, elastically reflected electrons may cause secondary electron emission from the collector; in investigations of the photoemissive effect emission may occur from the collector due to diffusely scattered light. The dependence of the reverse current on the potential difference between the collector and the target is calculated.

Dispersion Relations for Tensor Media and their Application to Ferrites—B. S. Gourary. (J. Appl. Phys., vol. 28, pp. 283–288; March, 1957.) "The well-known Kronig-Kramers integral relations between the real and imaginary parts of the susceptibility are generalized to the case where the susceptibility is a tensor. The consequences of the principle of energy conservation are discussed. The case of a ferrite is discussed in some detail."

Criterion for Uniform Micromagnetization
—W. F. Brown, Jr. (*Phys. Rev.*, vol. 105, pp. 1479–1482; March 1, 1957.) An initial uniform state is compared with all neighboring states, uniform or nonuniform, as an initially large

applied field decreases.

538.221:538.569.4 2724
Ferromagnetic Relaxation by the Exchange Interaction between Ferromagnetic and Conduction Electrons—A. H. Mitchell. (Phys. Rev., vol. 105, pp. 1439–1444; March 1, 1957.) The relaxation time calculated from this mechanism is too long to account for the observed

line width in nickel. The exchange reaction may be dominant in other materials having narrower lines than nickel.

538.56:535.42

Extension of Babinet's Principle to Absorbing and Transparent Materials, and Approximate Theory of Back-Scattering by Plane, Absorbing Disks-H. E. J. Neugebauer. (J. Appl. Phys., vol. 28, pp. 302-307; March, 1957.) Calculations are made for circular disks of various reflection coefficients from zero to unity. Experimental results of Severin and v. Baeckmann (2693 of 1951) support the theory.

538.561.029.6: [621.373+621.375.9 Negative-Temperature Reservoir Ampli-

fiers—H. Motz. (J. Electronics, vol. 2, pp. 571-578; May, 1957.) Theoretical discussion of the principles of maser operation, with application to the conditions for oscillation in a cavity and for amplification in a transmission

538.569.4:535.33/.34

Plane Parallel Plate-Transmission-Line Stark Microwave Spectrograph-S. A. Marshall and J. Weber. (Rev. Sci. Instr., vol. 28, pp. 134-137; February, 1957.)

538.569.4:621.372.029.64

Molecules and Microwaves-(Electronic Radio Eng., vol. 34, pp. 254-257; July, 1957.) The basic principles of molecular absorption and emission of energy with particular reference to ammonia is discussed and the operation of molecular amplification by stimulated emission of radiation is described.

538,569,4,029,6;621,372,413 2729

A Precision Paramagnetic-Resonance Spectrometer-K. D. Bowers, R. A. Kamper, and R. B. D. Knight. (J. Sci. Instr., vol. 34, 49-53; February, 1957.) An accuracy within 3 parts in 10<sup>6</sup> is claimed.

537/539

Solid-State Physics [Book Review]-F. Seitz and D. Turnbull (eds.). Publishers: Academic Books, London; vol. 1, 469 pp., 1955; vol. 2, 469 pp., 1956. (Phys. Chem. Solids, vol. 1, p. 128; September/October, 1956.) First of a series of volumes reviewing progress in different fields and planned to appear initially twice a year.

## GEOPHYSICAL AND EXTRATER-RESTRIAL PHENOMENA

523.16

A Survey of Cosmic Radio Emission at 600 Mc/s-J. H. Piddington and G. H. Trent. (Aust. J. Phys., vol. 9, pp. 481-493; December, 1956.) The celestial sphere was surveyed at Sydney, Australia, between declinations 90° S and 51° N using a 3.3° wide beam. When reduced to isophotes and plotted in celestial coordinates (epoch 1955), the results determined a galactic pole at  $l \approx 330^{\circ}$ , b-89.1° (Lund coordinates) with the sun at about 50 parsecs north of the galactic plane. See also 2707 of 1956.

523,16

An Investigation of the Radio Source 06N2A in Gemini-H. Rishbeth. (Austr J. Phys., vol. 9, pp. 494-504; December, 1956.) During a lunar occulation the intensity of the source was reduced by over one fifth. The emission at meter wavelengths is mainly nonthermal.

523.16:523.72:621.396.677.3

Interferometer for the Study of Localized Solar Sources of Centimetre Waves-I. Alon, M. R. Kundu, and J. L. Steinberg. Acad. Sci., Paris, vol. 244, pp. 1726-1729; March 25, 1957.) The interferometer has two antennas 60 m apart on an east-west line. It was

used for observations at 3.23 cm \u03b1. Sources have an apparent diameter of 1 foot.

523.16:523.74

Observation of Radio-Frequency Solar Storms by means of the Great Nançay Interferometer-Y. Avignon, E. J. Blum, A. Boischot, R. Charvin, M. Ginat and P. Simon. (C.R. Acad. Sci., Paris, vol. 244, pp. 1460-1463; March 11, 1957.) The diameter, duration, altitude, and conditions of formation were established by daily observations. See also 3644 of 1956 (Blum, et al.).

523 16:551.510.535:538.566

Refraction of Extraterrestrial Radio Emission in the Atmosphere-W. A. Belyaev. (Astronom. Zh., vol. 32, pp. 359-372; July/August, 1955.) Refraction due to a quiet unperturbed ionosphere and atmosphere is considered assuming that the electron-density height distribution in the layers is parabolic. Calculations indicate that below about 100 mc ionospheric refraction exceeds molecular refraction.

523.16:621.396.677.833

A New Form for a Giant Radio Telescope-A. K. Head. (Nature, London, vol. 179, pp. 692-693; April 6, 1957.) The main reflector is a hemisphere of 250-foot radius which may be partly below ground. A small reflector designed to focus beams from the main reflector rotates in equatorially mounted bearings which are supported by a tripod and mounted at the center of the hemisphere. This form is claimed to be easier to construct than the usual steerable parabolic reflector of 250 feet or larger diameter.

523.5:621.396.67.012.12:621.396.11.029.62

Height-Gain in the Forward-Scattering of Radio Waves by Meteor Trails-Hines and O'Grady. (See 2892.)

523.53:621.396.96

Radio Echo Observations of Meteor Activity in the Southern Hemisphere-C. Ellyett and C. S. L. Keay. (Aust. J. Phys., vol. 9, pp. 491-480; December, 1956.) Most meteoric matter incident on the southern hemisphere down to magnitude +4.5, is confined to direct orbits closely following the plane of the ecliptic. Increase of observation sensitivity shows that many of the meteors previously regarded as sporadic represent the upper limit of showers of minor-sized particles, which are present during months normally regarded as devoid of showers.

523.72

Solar Radiation and Atmospheric Attenuation at 6-Millimetre Wavelength-R. N. Whitehurst, J. Copeland, and F. H. Mitchell. (J. Appl. Phys., vol. 28, pp. 295-298; March, 1957.) A Dicke-type radiometer was used. The total vertical attenuation on clear summer days is 1.2 db and is 1 db higher for a thin overcast. The effective solar temperature in mid 1956 was 4500°K.

Determination of the Velocity of Corpuscles, Ejected from the Active Regions of the Sun, from the Time of Delay of Phenomena on the Earth-V. A. Petukhov. (Bull. Acad. Sci. U.R.S.S., sér. géophys., no. 1, p. 124; January, 1957. In Russian.) Brief note drawing attention to the fact the corpuscles are not necessarily ejected radially from the sun.

523.74+523.72]:551.510.535

Relations between the Sun and the Ionosphere-(Nature, London, vol. 179, pp. 804-806; April 20, 1957.) Summarized report of a discussion at the Royal Astronomical Society on February 22, 1957, where short papers were read dealing with the great solar flare of February 23, 1956 and the solar-cycle variation of the sun's ionizing radiation.

550.37/.38:35.083

Experimental Investigation of the Natural Electromagnetic Field of the Earth in the Frequency Spectrum from 2 to 300 c/s-B. S. Enenshtein and L. E. Aronov. (Bull. Acad. Sci. U.R.S.S., sér. géophys., no. 1, pp. 62-70; January, 1957. In Russian.) Apparatus for the determination of the horizontal electric and the three magnetic components is described and its use in field measurements is outlined. Oscillograms of some typical records are shown. The field strength varied considerably with time with a mean value of about 30-50  $\mu v/km$ for the horizontal components of the electric field; the field strength of the horizontal magnetic components was of the order of  $10^{-9}$ oersted.

550.371:523.5

Influence of the Meteoric Stream of the Perseids on the Electric Field of the Earth's Atmosphere—M. V. Okhotsimskaya. (Bull. Acad. Sci. U.R.S.S., sér. géophys., no. 1, pp. 122-123; January, 1957. In Russian.) Records at the Alma-Ata station situated at a height of 1800 m above sea level indicate that the percentage decrease of the potential gradient on August 18-19 relative to the normal value was 28 per cent in 1952, 31 per cent in 1953, 10 per cent in 1954, and 24 per cent in 1955. The observed effect may be due to processes occurring in the E layer by telemeteorites or by their screening effect.

551 510 5:551 503:537 5 08

A Spectrophotometric Investigation of the Air Afterglow—D. T. Stewart. (J. Atmos. Terr. Phys., vol. 10, pp. 318-319; 1957.) Further evidence that the spectral continuum having a short-wavelength limit at 3700 Å can be attributed to the nitrogen dioxide molecule.

551.510.5:551.594.5

The Red and Near Infrared Auroral Spectrum—A. Omholt. (J. Atmos. Terr. Phys., vol. 10, pp. 320-331; 1957.) The results of intensity measurements in the range 5400-8800 Å.

551.510.5:551.594.5:621.396.822

Low-Frequency Radio Emission Aurorae-G. R. Ellis. (J. Atmos. Terr. Phys., vol. 10, pp. 302-306; 1957.) A possible contribution to the level of continuous noise observed at hundreds of kc may be Cherenkov radio emission originating from the incidence of auroral particles on the upper ionosphere. If the Cherenkov process is valid, the frequency range of the emission would extend from a few hundred kc to the low-audio frequencies.

The Present State of Knowledge concerning the Lower Ionosphere-A. H. Waynick.

(Proc. IRE, vol. 45, pp. 741-749; June, 1957.) A review of recent progress resulting from radio measurements and rocket sounding. Seventyeight references.

550.510.555 Analysis of Fading Records from Four Spaced Receivers for Ionospheric Wind Measurements-M. S. Rao and B. R. Rao. (J. Atmos. Terr. Phys., vol. 10, pp. 307-317; 1957.) The advantages of a four-receiver system and an improved method of analyzing results are discussed.

551.510.535

Diffraction Microscopy and the Ionosphere -G. L. Rogers. (J. Atmos. Terr. Phys., vol. 10, pp. 332-337; 1957.) Improvements in the interpretation of existing Mitra fading patterns, used in the determination of ionosphreic movement, through the application of diffraction microscopy technique are shown to be slight; 551,510,535

Movements of Ionospheric Irregularities Observed Simultaneously by Different Methods-I. L. Jones, B. Landmark, and C. S. G. K. Setty. (J. Atmos. Terr. Phys., vol. 10, pp. 296-301: 1957.) Horizontal movements of large Flayer and E-layer irregularities were traced by recording "bursts" of amplitude received from three transmitters about 15 km apart, and by other methods. It was concluded that the large irregularities had the same movements as those irregularities producing ordinary fading.

551.510.535 2751

Motion in the Night-Time Es Region at Brisbane-J. A. Thomas and M. J. Burke. Aust. J. Phys., vol. 9, pp. 440-453; December, 1956.) Speeds of movement are grouped about 70 m, and the winds are predominantly towards the north.

551.510.535

Double-Layer Phenomena in the Es Region—J. A. Thomas. (Aust. J. Phys., vol. 9, pp. 574–577; December, 1956.) P'f and P't records are shown on which both "sequential"  $E_s$ " and constant-height  $E_s$  are present. Occasional records also show "stacks" of  $E_{\delta}$  echo traces which are attributed to multiple hops between the  $E_s$  layers.

The Behaviour of a Chapman Layer in the Night F2 Region of the Ionosphere, under the Influence of Gravity, Diffusion, and Attachment—R. A. Duncan. (Aust. J. Phys., vol. 9, pp. 436–439; December, 1957.) "It is shown that, in the presence of diffusion, gravity, and attachment, a Chapman layer, no matter what its height, maintains its shape, decaying uniformly with an effective attachment coefficient equal to the true attachment coefficient at the height of the electron density maximum; and that, at the same time, the layer drifts bodily towards an equilibrium height. It is then shown that a uniform vertical tidal drift will alter the equilibrium height of a Chapman layer."

551.510.535:621.396.11 2754

Reflection at a Sharply-Bounded Ionosphere—I. W. Yabroff. (PROC. IRE, vol. 45, pp. 750-753; June, 1957.) "A quantitative description of the waves transmitted into and reflected from a sharply-bounded, anisotropic ionosphere with losses is given. Given curves show the effects of the earth's field and losses for a particular model of the nighttime E layer at vlf."

The Dependence of Point-Discharge Currents on Wind as Examined by a New Experimental Approach-M. I. Large and E. T. Pierce. (J. Atmos. Terr. Phys., vol. 10, pp. 251-257; 1957.) "Experiments are described in which a metal point mounted in the open air is artificially raised to a high potential V and the resulting point-discharge current I is measured. The relation  $I = A(V - V_0)(W^2 + c^2V^2)^{\frac{1}{2}}$ , where A and c are constants, W the wind speed, and  $V_0$  the onset potential, is found to fit the results reasonably well."

Point Discharge from an Isolated Point-J. R. Kirkman and J. A. Chalmers. (J. Atmos. Terr. Phys., vol. 10, pp. 258-265; 1957.) The discharge current I from a point mounted on a mast was measured and related to wind speed W and natural potential gradient F. The results and those of earlier workers are shown to fit a formula I = K(W+c)(F-M), where c and M are constants.

Relations between the Character of Atmospherics and their Place of Origin-J. Chapman and E. T. Pierce. (PRoc. IRE, vol. 45, pp. 804-806; June, 1957.) Waveforms of atmospherics from similar distances but different directions have been found to differ even when the ionospheric conditions along the two paths were apparently similar. The different conductivities of land and sea offer one humble explanation.

551.594.6 2758

Atmospheric Waveforms with Very-Low-Frequency Componants below 1 kc/s known as Slow Tails-F. Hepburn. (J. Atmos. Terr. Phys., vol. 10, pp. 266-287; 1957.) Observed characteristics are explained by a critical application of Hales' waveguide theory (2888 of 1948) for propagation between the earth and a homogeneous layer with a lower boundary. The height of this boundary during the day is different from that at night,

551.594.6:621.317.35

A Technique for the Rapid Analysis of Whistlers-J. K. Grierson. (Proc. IRE, vol. 45, pp. 806-811; June, 1957.) A proposal for a machine in which the whistlers are recorded magnetically, and successive small samples are played back repeatedly, at high speed, through a filter of rapidly varying frequency.

551.594.6:621.396.11.029.45 2760

Very-Low-Frequency Radiation from Lightning Strokes-E. L. Hill. (PROC. IRE, vol. 45, pp. 775-777; June, 1957.) Derivation of the frequency spectrum and total radiated power from an idealized model of the return stroke.

551.594.6:621.396.822

Noise Investigation at V.L.F. by the National Bureau of Standards-W. Q. Crichlow. (Proc. IRE, vol. 45, pp. 778-782; June, 1957.) A brief description of new equipment for the measurement of atmosphereic noise, and a discussion of the most recent presentation of data on a world-wide basis.

551.594.6:621.396.822

Some Recent Measurements of Atmospheric Noise in Canada-C. A. McKerrow. (Proc. IRE, vol. 45, pp. 782-786; June, 1957.) Measurements of noise power at 10 kc and 107 kc, and a comparison with previous data. Highest noise levels were in summer, but a smaller maximum occurred in winter.

551.594.6:621.396.822

Characteristics of Atmospheric Noise from 1 to 100 kc/s-A. D. Watt and E. L. Maxwell. (PROC. IRE, vol. 45, pp. 787-794; June, 1957.) The frequency spectrum of the radio energy of a lightning flash is derived from the waveform of the current distribution. The results are combined with propagation data to determine the field at a distance, Amplitude probability distributions of received noise are plotted.

523.78:551.510.535 2764

Solar Eclipses and the Ionosphere [Book Reviewl-W. J. G. Beynon and G. M. Brown (eds.). Publishers: Pergamon Press, London and New York, 330 pp., 1956. (Nature, London, vol. 179, p. 711; April 6, 1957.) An account of the proceedings at a symposium held in London, August, 1955, giving fifty-three formal papers in full, brief accounts of discussions, and a comprehensive bibliography.

## LOCATION AND AIDS TO NAVIGATION

621.396.933

Automatic Position Plotting-(Engineer, London, vol. 203, p. 344; March 1, 1957.) A system of automatic triangulation of a number of bearings by means of luminous traces on a glass screen to determine the position of aircraft is briefly described. High-intensity projection cr tubes are used and the bearing information can be transmitted via telephone circuits or radio links.

621.396.933.2:621.396.677

D.F. Aerial System for Decimetre Wavelengths—Clarke. (See 2674.)

621.396.96:621.396.677.833.2

2767

A New Type of Surveillance [radar] Aerial: a Paraboloid Illuminated by a Slotted Waveguide—Thoural. (See 2678.)

621.396.96:621.396.822:621.317.3 2768

Measurement of Noise Factor in Centimetric Radar.—N. N. Patla. (J. Inst. Telecommun. Eng. India, vol. 3, pp. 32-37; December, 1956.) A description of methods in which the noise factors of the IF amplifier and the complete receiver are measured by means of noise diodes and gas-discharge tubes, respectively.

621.396.962.21

Note on an Approximation Method of Forecasting the Distortion of Equiphase Hyperbolae where they Cross Coast Lines-P. Hugon. (Ann. Radioélect., vol. 12, pp. 78-83; January, 1957.) Approximate formulas for the coastline correction were applied to a provisional Decca chain in Southern France: fair agreement with practical measurements was found.

621.396.963.083.7

Remote Presentation of Radar Information by Microwave Link-G. J. Dixon and H. H. Thomas. (J. Brit. IRE, vol. 17, pp. 193-209; April, 1957.) The basic problems and possible systems are reviewed. An equipment operating at 4 kmc using pulse time modulation is described in detail.

621.396.965.088:621.396.677.859

Measuring Radome Tracking Error-J. B. Damonte and A. F. Gaetano. (Electronic Ind. Tele-Tech., vol. 16, pp. 66, 128, 132; January, 1957.) A quick and accurate method of measuring the error.

#### MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:546.368.63

The Characterization and Crystal Structure of Caesium Antimonide, a Photoelectric Surface Material-K. H. Jack and M. M. Wachtel. (*Proc. Roy. Soc. A*, vol. 239, pp. 46-60; February 12, 1957.) X-ray investigation shows that it is a "normal-valency" intermetallic compound with a small range of homogeneity near to the composition Cs3Sb. The atomic arrangement is pseudo-body-centered cubic with a defect structure based upon the B32 sodium thallide type (NaTl).

535.215:546.471.241

CdS-Type Photoconductivity in ZnTe Crystals-R. H. Bube and E. L. Lind. (Phys. Rev., vol. 105, pp. 1711-1715; March 15, 1957.) Photoconductivity measurements on ZnTe single crystals show that the mechanism proposed for photoconductivity phenomena in CdS and CdSe may also be applied to ZnTe.

535.215: [546.817.231+546.817.241

PbSe and PbTe Infrared Detectors-T. Piwkowski. (Acta Phys. Polon., vol. 15, pp. 271-274; 1956. In English.) PbTe photoconductive and photovoltaic layers prepared by a known evaporation method retain their properties when exposed to the air but similar PbSe layers do not. A new evaporation method of preparing PbSe layers overcomes this disadvantage. Nineteen references.

535.215:546.817.231

Photoconductivity of Lead Selenide: Theory of the Mechanism of Sensitization-J. N. Humphrey and R. L. Petritz. (Phys. Rev., vol. 105, pp. 1736-1740; March 15, 1957.) Various models for the mechanism of photoconductivity are examined in relation to experimental results on the sensitization of

PbSe films by O. S. Se and the halogens. It is concluded that the only satisfactory model is one in which minority-carrier traps are introduced and the majority-carrier lifetime increased by the sensitizing agent.

A Note on the Diffusion-Controlled Processes in Luminescent Solutions-A. Jabloński. (Acta Phys. Polon., vol. 15, pp. 263-266; 1956. In English.)

535.37: [546.472.21+546.482.21.

De-excitation of ZnS and ZnCdS Phosphors by Electric Fields-H. Kallmann and P. Mark. (Phys. Rev., vol. 105, pp. 1445-1450; March 1, 1957.) The effect of strong applied ac and dc fields on the rise and decay of photoconductivity in ZnS and ZnCdS phosphors is described. The electron fields accelerate the deexcitation process. This phenomenon is attributed to the reduction of retrapping of excited electrons.

535.37:546.561-31

A New Luminescence Emission in Cu2O-J. Bloem, A. J. Van der Houven van Oordt, and F. A. Kröger. (Physica, vol. 22, pp. 1254-1256; December, 1956.) Infrared luminescence characteristics measured at 77° and 20°K are shown as a function of oxygen pressure during preparation.

535.376

Electroluminescence Deterioration-W. A. Thornton. (J. Appl. Phys., vol. 28, pp. 313-316; March, 1957.) The slow decrease in luminescence with time has been studied in conjunction with various associated effects. The observations are consistent with trap and donor depletion by electrolysis.

Crystal Mount and Techniques for Measuring High-Frequency-Induced Electroluminescence-G. G. Harman. (Rev. Sci. Instr., vol. 28, pp. 127-129; February, 1957.) The apparatus includes a simple optical system for irradiation and for separation of excitation and luminescence spectra. Excitation frequencies ranging from dc to to 400 mc, and also in selected microwave bands, may be used.

537.226/.227:546.431.824-31

Activation Field and Coercivity of Ferroelectric Barium Titanate-H. H. Wieder. (J. Appl. Phys., vol. 28, pp. 367-369; March, 1957.) Measurements obtained from hysteresis loop data may be used to calculate the activation field. The fields calculated lead to conclusions relating to the properties of the crystals.

537,226/,227:547,476,3

Electric Strength of Rochelle Salt Crystals at a Constant, Alternating (50 c/s) or Pulse Voltage of 10<sup>-4</sup>-10<sup>-7</sup> sec Duration—K. M. Kevroleva. (Zh. Tekh. Fiz. vol. 26, pp. 2243-2247; October, 1956.) The dependence of breakdown voltage gradient on the thickness of the crystals, crystal axis, temperature, and time was investigated experimentally. Results show that the breakdown strength decreases with increasing thickness, that it is independent of temperature in the range  $-60^{\circ}$ C to  $50^{\circ}$ C, and no changes occur at the Curie temperatures  $(-18^{\circ}\text{C and } +24^{\circ}\text{C})$ , that it is independent of the crystallographic axis, and that it increases with decreasing pulse duration.

Mechanism of Dielectric Relaxation Losses in Crystals with Polar Molecules—I. Ts. Lyast. (Zh. Tekh. Fiz., vol. 26, pp. 2293–2301; October, 1956.) The complex permittivity is calculated assuming the following mechanism: the relaxation dielectric losses are connected with the migration of polar molecules to unoccupied positions; this movement is, in general, accompanied by rotation of the polar

molecule, resulting in relaxation polarization of the crystal. Theoretical and experimental results are compared for gypsum.

2784 537.226.31

Dielectric Losses in Dense Amorphous Structures-V. Kh. Kozlovski, (Zh. Tekh. Fiz., vol. 26, pp. 2254-2258; October, 1956.) The losses are considered theoretically taking into account the inertia of ions. The frequency characteristic of the real and imaginary parts of the dielectric constant is calculated for particular cases.

537.227/.228:061.3(47)

1st Conference on Ferroelectricity (Leningrad, 19th-24th June 1936)—(Bull. Acad. Sci. U.R.S.S., sér. phys., vol. 21, pp. 233-292; February, 1957. In Russian.) Texts are given of the following five papers presented at the conference:

Brief Review of Some Results of Investigations of Ferroelectrics in Recent Years-

G. A. Smolenski (pp. 233-263).

Orientation of Domains and Macrosymmetry of Properties of Ferroelectric Single Crystals—I. S. Zheluder and L. A. Shuvalov (pp. 264-274).

Crystal Chemistry of Ferroelectrics with Perovskite-Type Structure—Yu. N. Venevtsev

and G. S. Zhdanov (pp. 275-285).

The Characteristic of the Change of Domain Structure of Rochelle Salt in Alternating Electric Fields-I. S. Zheludev and R. Ya. Sit'ko (pp. 286-288).

Some Details of Domain Structure of Rochelle Salt Crystals (from Optical Observations)-M. A. Chernysheva (pp. 289-292).

537.227:546.431.824-31

Infrared-Absorption Studies on Barium Titanate and Related Materials-J. T. Last. (Phys. Rev., vol. 105, pp. 1740-1750; March 15, 1957.) Absorption bands, arising from normal vibrations of the TiO3 group, have been measured; they are centered on wave numbers of  $495 \text{ cm}^{-1}$  and  $340 \text{ cm}^{-1}$ .

537.311.31:538.63

2787 Magnetoresistance Effects in the Group I Metals at High Fields-R. G. Chambers. (Proc. Roy. Soc. A, vol. 238, pp. 344-357; January 8, 1957.) Resistivity and Hall coefficient were measured in Cu, Ag, and Au at 4°K in fields up to 25 kg.

537.311.31:538.63

Magnetoresistance—New Tool for Electrical Control Circuits—R. K. Willardson and A. C. Beer. (Elec. Mfg., vol. 57, pp. 79-84; January, 1956.) Review of principles and applications.

537,311,33

General Semiconductor Junction Relations N. H. Fletcher. (J. Electronics, vol. 2, pp. 609-610; May, 1957.) General carrier density relations are derived for an abrupt junction between two sections of semiconductor with arbitrary impurity contents and with an arbitrary applied bias.

537.311.33

Drift of Minority Carriers in the Presence of Trapping-A. K. Jonscher. (Proc. Phys. Soc., London, vol. 70, pp. 223-229; February 1, 1957.) Expressions are derived for the densities of free carriers,  $N_t$ , and trapped carriers,  $N_t$ , as functions of distance and time, ignoring the effects of diffusion. The N/time-response curve depends critically on the steady-state carrier lifetime, the trapping time constants, and on the distance of the collector from the emitter.

Diffusion of Minority Carriers in the Presence of Trapping-A. K. Jonscher. (Proc. Phys. Soc., London, vol. 70, pp. 230-234; February 1, 1957.) For constant-level carrier density, the diffusion is little affected by trapping in extrinsic material; if the density varies sinusoidally the effective diffusion length is the same as for the trap-tree case at low and high frequencies but is appreciably less at intermediate frequencies.

2792 537.311.33

Possible Mechanism for Radiationless Recombination in Semiconductors-L. Bess. (Phys. Rev., vol. 105, pp. 1469-1478; March 1, 1957.) Two Auger-type processes are described and evaluated whereby the trapping of a hole or electron results in the emission of an energetic hole or electron instead of a photon. These radiationless processes predominate over the radiative process under nearly all operating conditions for a wide class of semiconductors.

537.311.33 Fluctuations in the Number of Electrons

and Holes in a Semiconductor-D. J. Oliver. (Proc. Phys. Soc., London, vol. 70, pp. 244-247; February 1, 1957.) Statistical mechanics are used to extend previous work [793 of 1956] (Burgess)] to include semiconductors in which electrons and/or holes form a degenerate assembly.

537.311.33 Theory of Semiconductors of Type AIIIBV-

A. I. Gubanov (Zh. Tekh. Fiz., vol. 26, pp. 2170-2178; October, 1956.) Critical comment on Seraphin's theory (1379 of 1955). A semiquantitative model is presented clarifying the widening of the forbidden zone in compounds of the AIIIBV type in comparison with isoelectron elements of Group IV.

537.311.33

Electronic Properties of Aromatic Hydrocarbons: Part 3-Diffusion of Excitons-O. Simpson. (*Proc. Roy. Soc. A.*, vol. 238, pp. 402–411; January 8, 1957.) A method is described by which the migration of excitons in anthracene can be observed. For Parts 1 and 2, see 2093 of 1956.

537.311.33:061.3(47)

8th All-Union Conference on Semiconductors (Leningrad, 15th-21st November, 1955)-(Bull. Acad. Sci. U.R.S.S., sér. phys., vol. 20, pp. 1467–1580; December, 1956; vol. 21, pp. 1–159, and pp. 161–224; January, February, 1957. In Russian.) Texts are given of papers presented in the following sections: a) electrical and thermal properties of semiconductors, b) theory of semiconductors, c) chemistry of semiconductors, and d) semiconductor catalysis. The papers include:

Thermal Equilibrium of Electrons in Surface and Bulk Levels in a Semiconductor-

E. Lashkarev (pp. 1469-1478).

Thermoelectric Phenomena in Semiconductors with a Non-equilibrium Concentration of Current Carriers-Ya. Tauts [Tauc] (pp. 1479-1483).

Appearance of Photoelectromotive Force in an Illuminated Semiconductor in an Inhomogeneous Magnetic Field-Ya. Tauts [Tauc] (pp. 1484-1485).

Structure and Electrical Properties of Indium Antimonide in Thin Layers-I. D. Konozenko and S. D. Mikhnovski (pp. 1486-

Investigation of the Peltier Effect and Thermoelectromotive Forces in Germanium-M. Shtenbek and I. I. Baranski (pp. 1491-

New Vitreous Semiconductors-N. Goryunova and B. T. Kolomiets (pp. 1496-1500)

Semiconductor Properties of Magnesium-Bismuth Alloys-A. K. Kikoin and G. D. Fedorov (pp. 1501-1508).

Electrical Properties of Manganese-Germanium Alloys-I. G. Fakidov, N. P. Grazhdankina, and V. N. Novogrudski (pp. 1509-1518).

New Type of Thermal Acceptors in Germanium-V. A. Zhidkov and V. E. Lashkarev (pp. 1521-1525).

Diffusion of Antimony and Zinc from the Vapour Phase into Germanium-V. E. Kosenko (pp. 1526-1532),

Thermomechanical Phenomena in Thin Layers of Semiconductors-I. G. Nerkashevich (pp. 1533-1540).

Temperature Dependence of the Electrical Conductivity of Organic Semiconductors-A. T. Vartanyan (pp. 1541-1547).

Dependence of the Mobility of Current Carriers in Germanium on the Concentrations of Antimony and Phosphorus-P. I. Baranski (pp. 1548-1549).

Theory of Electric Strength of Germanium and Silicon-V. A. Chuenkov (pp. 1550-1552).

Electron Density Distribution and Electrical Conductivity of Cadmium Sulphide Crystals-Yu. N. Shuvalov (pp. 1553–1559).

An Attempt to Determine the Increase of Current Carrier Temperature Caused by an Electric Field in Germanium-M. Shtenbek (pp. 1560-1562).

Formation of Vacancies in a Crystal Lattice P. Kalabukhov (pp. 1563-1568).

Production of Phosphors by means of Recrystallization in Electron Migration-Z. D'yulai (pp. 1569-1570).

Electrical Properties and Uses of Silicon Carbide-N. P. Bogoroditski, V. V. Pasynkov, G. F. Kholuyanov, and D. A. Yaskov (pp. 1571-1580).

Spur Method for Conduction Electrons in Semiconductors: Part 1-Weak Interaction of Electrons with Oscillations. Part 2-Variational Method-M. A. Krivoglaz and S. I. Pekar (pp. 3-32).

Influence of the Polaron Effect on the Thermodynamics of Conduction Electrons in Semiconductors-M. A. Krivoglaz and S. I. Pekar (pp. 33-36).

Interaction of Excitons with a Molecular Lattice-E. I. Rashba (pp. 37-47).

Investigation of Crystal Micro-theory-B. Tolpygo (pp. 48-64).

Theory of Excitons in Ionic Crystals-I. M. Dykman (pp. 65-67).

Interaction of Localized Electrons with Acoustic Vibrations in Homopolar Crystals-M. F. Deigen (p. 68).

Recombination in a Collision of Current Carriers in Semiconductors-L. Sosnovski [Sosnowski] (pp. 70-73).

Excited States of Two-Electron Colour Centres in Ionic Crystals of  $\alpha$  and  $\beta$  Bands-O. F. Tomasevich (pp. 74-77).

Energy Spectrum of Exciton in Ionic Crystal -I. P. Ipatova (pp. 78-86).

A Recombination Mechanism of Current Carriers in Strongly Alloyed Semiconductors-L. Bonch-Bruevich (pp. 87-96).

Some Peculiarities in the Thermodynamics of the Phonon and the Electron Gas in a Solid Body—Yu. N. Obraztsov (pp. 97-102).

Mean Free Path of an Electron in Liquid and Amorphous Conductors-A. I. Gubanov (p. 104).

Interaction of Electrons of a Semiconductor with Lattice Vibrations at Very Low Temperatures-L. E. Gurevich (pp. 105-111).

Some Electroacoustic Effects-L. E. Gurevich (pp. 112-119).

Some Problems of the Crystal Chemistry of Compounds with Zinc Blende Structure-N. A. Goryunova (pp. 120-132).

Theory of Phases [of compounds] of Variable Composition with Zinc Blende Structure (Investigation of Possible Range of Homogeneity of Type A<sup>III</sup>B<sup>V</sup> Compounds)—B. F. Ormont, N. A. Goryunova, I. I. Ageeva, and N. N. Fedorova (pp. 133-140).

Physico-chemical Analysis of some Semi-

conductor Systems-N. Kh. Abrikosov (pp. 141 - 145

Crystallization of Single-Crystal Layers of Silicon and Germanium from the Gaseous Phase-N. N. Sheftal', N. P. Kokorish, and A. V. Krasilov (pp. 146-152).

Production of Single-Crystal Specimens of Cuprous Oxide-Yu. I. Gritsenko (pp. 153-

Investigation of the Coefficients of Self-Diffusion of I and K Ions in Alkali-Halide Crystals Irradiated by X Rays-V. V. Mumladze (pp. 158-159).

Effect of Adsorption on the Electrical Conductivity and Work Function of a Semiconductor-V. B. Sandomirski (pp. 211-219).

Absorption of Light in Crystals of Mercury Halides-E. F. Gross and A. A. Kaplyanski (pp. 220-224).

537.311.33:535.215

Kinetics of the Bipolar Photo-e.m.f. in a Semiconductor with Metal Electrodes-E. I. Kaplunova and K. B. Tolpygo. (Zh. Tekh. Fiz., vol. 26, pp. 2165-2169; October, 1956,)

#### 537.311.33:535.34

The Anomalous Skin Effect and the Optical Absorptivity of Semiconductors: Part 2-R. B. Dingle. (Physica, vol. 22, pp. 1237-1241; December, 1956.) More general expressions are derived by solving the integro-differential equation of the anomalous skin effect. Part 1: 1116 of 1957

#### 537.311.33:537.324:546.87.24.23

Solid Solutions Bi<sub>2</sub>Te<sub>2</sub>—Bi<sub>2</sub>Se<sub>3</sub> as Materials for Thermoelements—S. S. Sinani and G. N. Gordyaková. (Zh. Tekh. Fiz., vol. 26, pp. 2398-2399; October, 1956.) Brief note. The solid solutions, with various impurities, have a conductivity  $\sigma$  490–900  $\Omega^{-1} \cdot \text{cm}^{-1}$ , thermoelectric coefficient  $-\alpha$  225 to  $-180\mu\text{V/}^{\circ}\text{C}$ , and thermal conductivity  $\chi$  2.6-3.0×10<sup>3</sup> cal·cm<sup>-1</sup>deg<sup>-1</sup> · s<sup>-1</sup>.

#### 537.311.33:538.21

Magnetic Properties of Pure and n-Type Germanium at Liquid-Helium Temperatures-F. T. Hedgeock. (*J. Electronics*, vol. 2, pp. 513–528; May, 1957.) Susceptibility measurements at temperatures between 4.2°K and room temperature are reported for n-type Ge samples of various charge-carrier densities. In high-purity material an anomalous low-temperature paramagnetism was observed. For nondegenerate samples in a particular impurity concentration range, the results are consistent with the usual activation process, but below this concentration it seems necessary to suggest the existence of conduction in an impurity band.

#### 537.311.33:538.6 2801

D.C. Magnetoconductivity and Energy Band Structure in Semiconductors-R. M. Broudy and J. D. Venables. (Phys. Rev., vol. 105, pp. 1757-1763; March 15, 1957.) A general method is described for experimentally obtaining all components of the magnetoresistivity and hence the magnetoconductivity tensor. Expressions for determining the mass ratio Khave been derived. The known band structures of n-type Ge and Si have been verified by the method and K has been determined for Ge from 65°K to 200°K.

#### 537.311.33:538.6

The Galvanomagnetic and Thermomagnetic Effects in Semiconductors-R. Mansfield. (Proc. Phys. Soc., London, vol. 70, pp. 240-243; February 1, 1957.) The values of the coefficients are calculated for a semiconductor in which the charge centers are scattered by ionized impurity centers.

#### 537.311.33:538.63 2803

Theory of the Hall and Nernst Effects in a Semiconductor with an Impurity Zone-M. I.

Klinger, V. G. Novikova, and V. N. Agarkova. (Zh. Tekh. Fiz. vol. 26, pp. 2185-2194; October, 1956.) The Hall effect, R, and the Nernst effect, Q, are first considered for a metal with a narrow conduction zone and then for a semiconductor with an impurity zone. The functions R(T) and O(T) are investigated and experimental results are compared with theory.

#### 537.311.33:538.63

Measurement of Gauss Effect in Various Semi-conductors at 10,300 and 600 Mc/s-P. Ramer, M. J. O. Strutt, and F. K. von Willisen. (Arch. elekt. Übertragung, vol. 11, pp. 1-7; January, 1957.) The Gauss effect is a galvanomagnetic effect in which the resistance of a semiconductor increases in a transverse magnetic field: it is directly connected with the Hall effect. Measurements on samples of InAs, InSb, and Ge show a slight decrease in galvanomagnetic effects at 10 mc and very pronounced falls at 300 and 600 mc compared to the values obtained at zero frequency. The experimental methods and errors and the limitations of existing theory are discussed.

#### 537.311.33:538.632

A Simple Graphical Method of Calculating the Density of Current Carriers in a Semiconductor from the Hall Coefficient-T. S. Robinson, M. Smollett, and R. G. Pratt. (Brit. J. Appl. Phys., vol. 8, pp. 130-131; March, 1957.)

#### 537.311.33: [546.28+546.289

Energy Band Structure in p-type Germanium and Silicon-E. O. Kane. (Phys. Chem. Solids, vol. 1, pp. 82-99; September /October, 1956.) Energy-band calculations are made for the three valence bands in Si and Ge in terms of the cyclotron resonance parameters. The energy in the band measured from k=0 is not assumed small compared with the spinorbit splitting. Matrix elements for direct optical transitions between valence bands and the free-carrier absorption are calculated.

2807

#### 537.311.33:546.28

Energy Levels in Electron-Bombarded Silicon—G. K. Wertheim. (Phys. Rev., vol. 105, pp. 1730-1735; March 15, 1957.) "Electron bombardment of n- and p-type silicon reduces the lifetime of minority carriers and decreases the carrier concentration. This paper presents evidence that: 1) an electron trapping level is located 0.16 ev below the conduction band and a hole-trapping level 0.29 ev above the valence band, 2) the recombination centers responsible for the reduction of lifetime in n type are located 0.31 ev from a band edge, and those in p type approximately 0.24 ev from a band edge. 3) lattice imperfections are produced at a rate of 0.18 per electron-cm of bombardment at 700 kev.

#### 537.311.33:546.28

Electrical and Optical Properties of Heat-Treated Silicon-W. Kaiser. (Phys. Rev., vol. 105, pp. 1751-1756; March 15, 1957.) effects of oxygen impurity in Si crystals pulled from a quartz crucible have been investigated by optical and electrical means after heattreatment at 450°C and 1000°C.

#### 537.311.33:546.28

Absorption Spectra of Impurities in Silicon: Part 1-Group III Acceptors-E. Burstein, G. Picus, B. Henvis, and R. Wallis. (Phys. Chem. Solids, vol. 1, pp. 65-74; September /October, 1956.) The spectra give information about the ionization energies and excited states of the impurity centers. The results are compared with a simple theoretical model.

#### 537.311.33:546.28

Absorption Spectra of Impurities in Silicon: Part 2-Group V Donors-G. Pincus, E. Burstein, and B. Henvis. (Phys. Chem. Solids,

vol. 1, pp. 75-81; September/October, 1956.) These spectra were measured at liquid helium temperature, and ionization energies and term schemes for these materials have been determined from the data. Part 1: 2809 above.

#### 537.311.33[546.28+546.289]:536.21

The Thermal Conductivity of Germanium and Silicon between 2 and 300°K-J. A. Carruthers, T. H. Geballe, H. M. Rosenberg, and J. M. Ziman. (Proc. Roy. Soc. A, vol. 238, pp. 502-514; January 29, 1957.) Measurements on single crystals of pure n-type and p-type Ge containing from 1014 to 1019 Group III impurity atoms per cm3 and on pure n-type and golddoped p-type Si are reported.

#### 537.311.33:546.281.26:535.3

Absorption of Light in Alpha SiC Near the Band Edge-W. J. Choyke and L. Patrick. (Phys. Rev., vol. 105, pp. 1721-1723; March 15,

#### 537.311.33:546.289

Vacuum Technology for Germanium-Z. Majewski. (Arch. Elektrotech., vol. 5, pp. 769-779; 1956.) The technological process used in the production of metallic Ge from the oxide of Polish origin is described and the equipment used in the production of single crystals is discussed. The methods of resistivity and lifetime measurement used in various stages of manufacture are briefly described and the results are given.

#### 537.311.33:546.289

Thermal Acceptors in Germanium-H. Letaw, Jr. (Phys. Chem. Solids, vol. 1, pp. 100-116; September/October, 1956.) Thermal acceptors in Ge are identified as vacancies with an energy of formation of 2 ev. In the annealing of Ge divacancies are initially formed, followed by clusters of higher order.

#### 537.311.33:546.289 2815

Storage of Injected Carriers at Surfaces of Germanium-B. H. Schultz. (Philips Res. Rep., vol. 12, pp. 82-96; February, 1957.) The effects of surface storage are calculated using standard space-charge theory. Measurements of the relaxation of photoconductance show the storage to be appreciable although the surface layer is very thin. The results are in qualitative agreement with theory.

#### 537.311.33:546.289

Investigation of Surface Conductivity and Surface Recombination in Germanium Specimens—A. V. Rzhanov, I. G. Neizvestnyi, and V. V. Roslyakov. (Zh. Tekh. Fiz., vol. 26, pp. 2142-2153; October, 1956.) Results of an experimental investigation are reported. A correlation is established between the changes in surface conductivity and the surface recombination velocity in Ge specimens in various gas media. This correlation is shown to be connected with changes in the surface potential which is evaluated.

#### 537.311.33:546.289 2817

Field Effect on an Illuminated Ge Surface and Investigation of the Surface Recombination Process-S. Wang and G. Wallis. (Phys. Rev., vol. 105, pp. 1459-1464; March 1, 1957.) From measurements of surface conductivity and photoconductivity on an etched Ge sample in the Brattain-Bardeen ambient cycle, values of surface potential and surface recombination velocity were derived. Dominant recombination centers with discrete levels were found near the center of the gap with a ratio of hole to electron capture probabilities of 9. The effect of a normal electric field was also studied and good agreement between theory and experiment obtained. This effect can be used as an additional tool to study the surface recombination centers.

#### 537.311.33:546.289

Recombination Radiation from Deformed and Alloyed Germanium p-n Junctions at 80°K-R. Newman. (Phys. Rev., vol. 105, pp. 1715-1720; March 15, 1957.) The recombination radiation from Ge p-n junctions shows an intrinsic band, peaked at 0.7 ev, and also a band peaked at about 0.5 ev which is attributed to mechanical strain. Junctions containing Cu show a radiation band at 0.59

#### 537.311.33:546.289:537.32

Some Aspects of Peltier Heating at Liquid /Solid Interfaces in Germanium-W. G. Pfann, K. E. Benson, and J. H. Wernick. (J. Electronics, vol. 2, pp. 597-608; May, 1957.) Uses of Peltier heating in growing single crystals, in producing n-p-n and n-p-n-p junctions in semiconductors, and in temperature-gradient zone melting, are discussed. The Peltier coefficient at the interface between the solid and liquid phases of a substance, may be determined from the velocity of interface movement due to Peltier heating.

#### 537.311.33:546.289:538.639

Nernst-Ettingshausen Effect in Germanium—R. I. Bashirov and I. M. Tsidil'kovski. (Zh. Tekh. Fiz., vol. 26, pp. 2195-2199; October, 1956.) Measurements on specimens of n- and p-type Ge in the temperature range 125-650°K are reported and the results are discussed.

#### 537.311.33:546.289:545.7

Determination of Gaseous Impurities in the Surface Layers of Germanium-S. M. Fainshtein and V. I. Fistul'. (Zh. Tekh. Fiz., vol. 26, pp. 2162-2164; October, 1956.) A massspectrometer used in conjunction with a vacuum extraction system was used. The method used and results obtained are briefly described.

#### 537.311.33:546.561-31

Diffusion of Chemical Admixtures in Cuprous Oxide and their Influence on its Rectification Properties-A. V. Sandulova and A. I. Andrievski. (Radiotekhnika i Elektronika, vol. 1, pp. 1492-1502; December, 1956.) Results are presented of an experimental determination of the diffusion coefficients for P32, S35, I131, and Au198 in cuprous oxides with various structures and of the influence of Ag110, S35, and I131 impurities and of excess oxygen on the electrical parameters of cuprous oxide rectifiers.

#### 537.311.33:546.621.86

Electrical and Optical Properties of Aluminium Antimonide; Action of Lithium-F. Kover and A. Quilliet. (C.R. Acad. Sci., Paris, vol. 244, pp. 1739-1741; March 25, 1957.) Alloying Li to the pure substance greatly increases the resistivity. It is suggested that the pure substance is composed of slightly more atoms of Al than of Sb and that Li atoms may fill the resulting gaps in its structure. See also 178 of 1957 (Kover).

#### 537.311.33:546.681.23.19

Arsenoselenides of Gallium-N. A. Goryunova and V. S. Grigor'eva. (Zh. Tekh. Fiz., vol. 26, pp. 2157-2161; October, 1956.) Brief report on X ray, surface microstructure, and quantitative analysis of compounds in the m GaAs. (1-m)Ga<sub>2</sub>Se<sub>3</sub> system. An electricalconductivity/composition curve is also given.

#### 537.311.33:546.682.86:535,215

Theory of the Spectral Distribution of Recombination Radiation from InSb-T. S. Moss. (Proc. Phys. Soc., London, vol. 70, pp. 247-250; February 1, 1957.) The theory explains satisfactorily the observed spectral distribution and indicates that 20 per cent of the total recombinations are radiative.

#### 537.311.33:548.0:621.385.833

The Examination of p-n Junctions with the Scanning Electron Microscope—C. W. Oatley and T. E. Everhart. (J. Electronics, vol. 2, pp. 568-570; May, 1957.) A technique for showing up junctions is described, with discussion of factors affecting contrast.

#### 537.311.33:549.351.12

Measurement of Electrical Conductivity of Crystals. Case of Chalcopyrite-M. Wintenberger. (C.R. Acad. Sci., Paris, vol. 244, pp. 1801–1803; March 25, 1957.) Valdes' fourprobe method for measuring conductivity (1502 of 1954) is applied to study the anisotropy of resistivity in CuFeS2. It is suggested that this increases with purity.

#### 537.533.8:546.331.31

2820

Secondary Electron Emission from a NaBr Single Crystal—T. L. Matskevich. (Zh. Tekh. Fiz., vol. 26, pp. 2399–2400; October, 1956.) The secondary emission coefficient  $\sigma$  was determined at 20, 50, and 300°C at normal primary electron beam incidence and at 20°C also at an angle of incidence of 50°. At 20°C, normal incidence and primary electron potential  $U_p$  1800 V,  $\sigma_{max}$ = 24 ±2, at 20°C, 50° incidence,  $U_p$  ≥ 3000 V,  $\sigma_{max}$ > 30. The coefficient is strongly temperature dependent.

#### 537.533.8:546.77 + 546.74

Secondary Electron Emission of Nickel and Molybdenum at Low Primary Electron Energies—A. R. Shul'man and E. I. Myakinin. (Zh. Tekh. Fiz., vol. 26, pp. 2223-2233; October, 1956.) Results show that there is a threshold value for secondary electron emission close to the work function. At primary electron energies  $V_p > \phi$  secondary electrons appear, their average energy increasing with increasing  $V_p$ . This can be explained by assuming spherically symmetric; scattering at low  $V_p$ values; i.e., different from the distribution at higher  $V_{\infty}$  values.

#### 537.58:546.832

Thermionic Constants and Sorption Properties of Hafnium-H. D. Hagstrum. (J. Appl. Phys., vol. 28, pp. 323-328; March, 1957.)

Analysis of Ferromagnetic and Antiferromagnetic Second-Order Transitions-J. A. Hofmann, A. Paskin, K. J. Tauer, and R. J. Weiss. (*Phys. Chem. Solids*, vol. 1, pp. 45-60; September/October, 1956.) Gives methods of separating the magnetic contribution to the specific heat of these materials.

Effect of the Interaction between Magnetic Particles on the Critical Single-Domain Size-A. H. Morrish and L. A. K. Watt. (Phys. Rev., vol. 105, pp. 1476-1478; March 1, 1957.)

The Electronic Properties of Nickel-Palladium Alloys—E. P. Wohlfarth. (Phys. Chem. Solids, vol. 1, pp. 35–38; September/October, 1956.) Theoretical predictions are made about the specific heat of these alloys, their electrical and magnetic properties, and the effect of compression on their Curie point.

Reproducing the Properties of Alnico Permanent-Magnet Alloys with Elongated Single-Domain Cobalt-Iron Particles-F. E. Luborsky, L. I. Mendelsohn, and T. O. Paine. (J. Appl. Phys., vol. 28, pp. 344-351; March, 1957.) A description of the synthesis of the magnetic properties of alnico alloys using fineparticle compacts.

Magnetic Alloy of High Permeability and Low Hysteresis Loss—(Engineer, London, vol. 203, p. 427; March 15, 1957.) Note of the magnetic properties of "supermendur," an alloy of 49 per cent Fe, 49 per cent Co, and 2 per cent Va developed by Bell Laboratories. Maximum permeability is 66000 at 20 kg, remanence 21.5 kg, and coercive force 0.26 oersted.

538.221 2836

Dynamax, a New Crystal and Domain-Oriented Magnetic Core Material—G. H. Howe. (Commun. & Electronics, no. 27, pp. 548–550; November, 1956. Discussion p. 551.) The high-permeability material described contains approximately 65 per cent Ni, 2 per cent Mo, and 33 per cent Fe. It is available as thin tape for toroidal cores; its dynamic characteristics are superior to those of other commercial rectangular-loop materials. The best values obtained are 1780000 maximum permeability, 11.95 kg residual flux density, and 0.0053 oersted coercive force.

538.221 2837

Superposed Magnetic Fields in Materials with Rectangular Hysteresis Loops—C. B. Wakeman and F. J. Beck. (Commun. & Elec. tronics, no. 27, pp. 562-569; November, 1956.) Report of experimental investigations of tubular, tape-wound specimens of Ni-Fe alloys, one containing 50 per cent Ni, and the other 79 per cent Ni and 4 per cent Mo.

538.221:621.317.411.029.63 283

On the Complex Permeability of Iron-Nickel Alloys at High Frequencies—J. C. Anderson and B. Donovan. (*Proc. Phys. Soc.*, vol. 70, pp. 186–191; February 1, 1957.) The internal resonance frequency in the anisotropic field varies with the composition; it is a minimum for 70 per cent Ni. The resonance curve for pure Ni has multiple peaks.

538.221:621.318.124 283

Ceramic Magnets—R. A. Scholten. (*Product Eng.*, vol. 27, pp. 143-148; December, 1956.) The characteristics and unit costs of barium ferrite magnets and the various grades of alnico magnets are tabulated for comparison. Some data are given on ceramic-magnet applications, particularly those utilizing their high coercivity.

538.221:621.318.124 284

Magnetic-Induction and Coercive-Force Data on Members of the Series  $BaAl_xFe_{12-x}O_{17}$  and Related Oxides—L. G. Van Uitert. (J. Appl. Phys., vol. 28, pp. 317-319; March, 1957.) The anisotropy field of the series increases with Al content causing ferromagnetic resonance to move to higher frequencies. Materials with extremely high coercive forces can thus be realized.

358.221:621.318.134

Magnesium-Copper-Manganese-Aluminium Ferrites for Microwave Applications—L. G. Van Uitert. (J. Appl. Phys., vol. 28, pp. 320–322; March, 1957.) The preparation of these ferrites is discussed and data presented on the saturation inductions, Curie temperatures, densities, and dc resistivities.

538.221:621.385.833:548.0 2842

Observation of the Domain Structure of a Ferromagnetic Material by means of Photoelectrons—G. V. Spivak, T. N. Dombrovskaya, and N. N. Sedov. (C.R. Acad. Sci. U.R.S.S., vol. 113, pp. 78–81; March 1, 1957. In Russian.) A photoelectron microscope and its applications are briefly described. The image on the fluorescent screen is obtained by magnetically focused photoelectrons emitted by the illuminated antimony-caesium film which covers the ferromagnetic material.

538.245 2843

Spontaneous Magnetization and Magnetic Susceptibilities of an Antiferromagnetic with Foreign Ions in Both Sublattices—K. F. Nies-

sen. (Phillips Res. Rep., vol. 12, pp. 69-81; February, 1957.)

38.245 2844

Formation of Magnetic Texture by a Magnetic Field in Thin Layers of Iron Obtained by the Electrolytic Method—N. V. Kotel'nikov. (C.R. Acad. Sci. U.R.S.S., vol. 113, pp. 97-99; March 1, 1957. In Russian.)

632

The Hall Effect in the Silver-Palladium Alloy System—A. I. Schindler. (*Phys. Chem. Solids*, vol. 1, pp. 42-44; September/October, 1956.)

2845

538.65 · 2846

The Interrelation of Magnetomechanical Phenomena and their Practical Applications—P. Ross. (Rev. gén. Elect., vol. 65, pp. 689-694; December, 1956.) After—summarizing the theory underlying these effects, the conditions are derived for obtaining the maximum magnetoelastic sensitivity and magnetomechanical coupling coefficient for a given ferromagnetic material.

539.23:537.311.3

Influence of the Support on Electrical Conductivity of Very Thin Films of Gold. Measurement of the Condenstation Factor—Sen-Sik Minn and S. Offret. (C.R. Acad. Sci., Paris, vol. 244, pp. 1624–1626; March 18, 1957.) An experimental study using supports of bismuth oxide, MgF<sub>2</sub>, and glass.

539.23:546.87:538.63 2848

Magnetoresistance of Thin Bismuth Films—P. Huet and A. Colombani. (C.R. Acad. Sci., Paris, vol. 244, pp. 1626–1629; March 18, 1957.) Experimental results are given in graphical form for fields up to 35 000 oersted and thicknesses between 25 and 2 800 Å. See also 2532 of 1957 and back references.

621.315.5/.6:539.16 2849

Designing Electronics to Resist Nuclear Energy—H. L. Morgan. (*Electronics*, vol. 30, pp. 155-157; May 1, 1957.) Materials and components must be selected that will function under conditions of high nuclear radiation and temperature, and low susceptibility to secondary radiation is essential to permit servicing of equipment. The properties of some materials are tabulated and discussed.

621.315.611:546.623-31 285

Electric Strength of Thin Layers of Aluminium Oxide—S. N. Koikov and A. N. Tsikin. (Zh. Tekh. Fiz., vol. 26, pp. 2248–2253; October, 1956.) An experimental investigation is reported of the dependence of electric strength on 1) the polarity of electrodes, 2) thickness of the oxide film in the range  $15-30\,\mu$ , and 3) temperature in the range  $300-2000^{\circ}\mathrm{K}$ . The breakdown of the oxide in air at normal temperatures is probably due to the breakdown of the air in the pores of the film; in vacuum the breakdown occurs 1) in the vacuum in the pores of the film and 2) along the surface of the pores. A thermal breakdown mechanism may be operative above  $1300-1400^{\circ}\mathrm{K}$ .

621.315.612.6:537.52

The Electric Strengths of Glasses with Different Sodium Contents—J. Vermeer. (*Physica*, vol. 22, pp. 1247–1253; December, 1956.)

,621.315.612.6:537.52

The Electrical Conduction of Glass at High Field Strengths—J. Vermeer. (*Physica*, vol. 22, pp. 1257–1268; December, 1956.) The dc ionic conductivity of four kinds of glass has been measured at different temperatures. Above ~100 kv/cm the final conductivity increased exponentially with field strength.

621.315.612.6:537.52 2853
On the Relation between Ionic Conduc-

tivity and Breakdown Strength of Glass—J. Vermeer. (*Physica*, vol. 22, pp. 1269-1278; December, 1956.)

#### MATHEMATICS

517.9:519.47 2854

Relation between a Criterion of Realizability and Functional Transformations—I. Gumowski. (C.R. Acad. Sci., Paris, vol. 244, pp. 1466-1468; March 11, 1957.) See also 1674 of 1957.

519.272 2855

A Scatter Diagram which Gives the Complex Correlation Coefficient for Normal Variables—N. F. Barber. (N.Z.J. Sci. Tech. B., vol. 38, pp. 366–374; January, 1957.) "The correlation coefficient between two complex variables u(t) and v(t) can, in certain cases, be estimated by forming a scatter diagram of the variable  $[u^x(t)+v(t)]$ . An experimental example is given."

#### MEASUREMENTS AND TEST GEAR

526.2:535.22

Precision of the Geodimeter as Affected by the Speed of Light in Air—D. T. Williams and J. R. Williams. (*Rev. Sci. Instr.*, vol. 28, pp. 108–115; February, 1957.) An analysis of the limitations imposed by uncertainties in the velocity of propagation of light in the atmosphere.

536.531:546.289 28

Germanium Resistance Thermometers Suitable for Low-Temperature Calorimetry—J. E. Kunzler, T. H. Geballe, and G. W. Hull. (Rev. Sci. Instr., vol. 28, pp. 96–98; February, 1957.) Details are given of their construction including the preparation of the crystal "bridges" and their manner of mounting inside a platinum capsule. The measured electrical properties of several samples are also given.

621.3.018.41(083.74) +529.786]:538.569.4 2858
Frequency Shift in Ammonia Absorption—
K. Matsuura, Y. Sugiura, and G. M. Hatoyama.
(J. Phys. Soc. Japan, vol. 11, p. 1301; December, 1956.) A shift in the frequency of the center of a microwave absorption line of ammonia was observed with change of state of the gas

621.3.018.41(083.74):621.396.11.029.45 2859 Intercontinental Frequency Comparison by Very-Low-Frequency Radio Transmission—J. A. Pierce. (PROC. IRE, vol. 45, pp. 794–803; June, 1957.) Discussion of the frequency stability of a 16-kc signal over paths 5 200 km and 18 700 km long. Measurements accurate to a few parts in 109 are possible in less than an hour.

621.317.2:621.373.421.13.029.63 2860

A Crystal-Controlled Signal Generator—M. T. Stockford. (*Electronic Eng.*, vol. 29, pp. 202-205; May, 1957.) Detailed description of equipment with an output of 5 w at 937.5 mc designed to drive a klystron Type VX8175 [2915 of 1956 (Norris)].

621.317.3:621.314.63 2861

Dynamic Methods of Testing Semiconductor Rectifier Elements and Power Diodes: Part 2—A. H. B. Walker and R. G. Martin. (Electronic Eng., vol. 29, pp. 220–224; May, 1957.) "Approximate" methods using normally available instruments are described. Direct comparison is made in certain cases between these measurements and those using the specialized equipment described in Part 1 (2544 of 1957). A useful test summary is tabulated.

621.317.3:621.396.822:621.396.96 2862 Measurement of Noise Factor in Centimetric Radar—Patla. (See 2768.) 621.317.35.029.426

621.317.34.029.62

Measurement of Group Delay in the 95- to 115-Mc/s Band-A. C. H. Borsboom. (Philips Telecommun. Rev., vol. 17, pp. 90-99; January, 1957.) Description of an instrument measuring delay variations with an accuracy of 10-9 sec.

621.317.35:551.594.6 A Technique for the Rapid Analysis of

Whistlers-Grierson (See 2759.)

A Continuous Amplitude/Time Analyser— W. A. P. Young. (Electronic Eng., vol. 29, pp. 206-209; May, 1957.) A twin-channel amplifier

and integrator for the band 16-30 cps for analyzing encephalographic records.

621.317.382.029.63/.64:537.52 2866

Effect of Microwave Signals Incident upon Different Regions of a D.C. Hydrogen Glow Discharge—B. J. Udelson. (J. Appl. Phys., vol. 28, pp. 380-381; March, 1957.) The change in voltage drop across a series resistor might be used to measure microwave power.

Instrument for Relative Measurements of Constant Magnetic Fields-I. S. Shpigel', M. D. Raizer, and E. A. Myae. (Radiotekhnika i Elektronika, vol. 1, pp. 1515-1519; December. 1956.) The instrument which utilizes the magnetic resonance absorption phenomenon, is designed for relative measurements of weakly inhomogeneous magnetic fields. The maximum measurable difference in the magnetic field is  $\Delta H_{max} = \pm 5$  per cent, where H is the field strength. The error in  $\Delta H$  is  $\pm 3-4$ per cent. Measurements were made of the injection-field distribution ( $H_0 = 150$  oersted) of the new 10-kmeV synchrophasotron of the Acedemy of Sciences.

621.317.726:621.385.832

The Measurement of Peak Voltage using a Cathode-Ray Tube-E. S. Fairley. (Brit. J. Appl. Phys., vol. 8, pp. 101-102; March, 1957.) A null method is used, a balance against an accurately determined direct voltage being

621.317.75:538.569.4

Direct Measurement of the Characteristic Moments of the Line Structure in Paramagnetic Resonance: Sinusoidal Sweep and Harmonic Analysis of the Signal-J. Hervé (C.R. Acad. Sci., Paris, vol. 244, pp. 1475-1478; March 11, 1957.)

621.317.755:621.385.029.63/.64

The Wamoscope-a Microwave Display Device-D. E. George. (Sylvania Technologist, vol. 10, pp. 5-7; January, 1957.) The "wamoscope" is a traveling-wave tube combined with a or tube screen in such a way as to make the brightness at the screen a function of the microwave power input.

#### OTHER APPLICATIONS OF RADIO AND ELECTRONICS

621.365.92

Radio-Frequency Carbonization-S. W. Taylor. (Research, London, vol. 10, pp. 108-115; March, 1957.) Apparatus for rf heating giving an extremely uniform distribution of heat is briefly described and results of experiments on various coals are given.

621.384.612

Strong Focusing in Particle Accelerators: Alternating-Gradient Synchrotrons-P. Lapostolle. (Onde élect., vol. 37, pp. 4-47; January, 1957.) Outline of underlying principles and brief description of 200-m diameter, 25-kmev synchrotron for CERN in Geneva [see also 3371 and 3372 (Grivet) of 1955].

621.384.622.1:535.42 Linear Accelerator with Preliminary Electron Bunching: Application to Electron Diffraction between 0.5 and 1 MeV-M. Papoular. (Ann. Phys., Paris, vol. 13, pp. 914-958; November/December, 1956,) Detailed description of the development and construction of a particle accelerator which incorporates a special device for preliminary bunching by velocity modulation to improve the energy spectrum (see also 1267 of 1957). Its application in electron diffraction techniques is outlined and illustrated by experimental results.

621.384.622.2

The 28-MeV Electron Accelerator Project for the Nuclear Research Centre at Saclay [France]-H. Leboutet, E. Picard, and J. Vastel. (Onde élect., vol. 37, pp. 28-35; January, 1957.) Basic design data of the linear accelerator and general description of the installation.

Tristable Gate moves C.R.O. Line Drawings-P. A. Ryan. (Electronics, vol. 30, pp. 178-180; May 1, 1957.) A means for producing simple contours on the face of a conventional

621.385.833

Properties of Two-Aperture Electron Lenses—G. D. Archard. (Brit. J. Appl. Phys., vol. 8, pp. 127–130; March, 1957.) "Spherical and chromatic aberrations and focal properties of two-aperture ('immersion') electron lenses are investigated theoretically, and the results are presented graphically as functions of lens geometry and voltage ratio."

621.398:621.396.934

Missile Telemeter uses Transistor Amplifier-J. H. Porter. (Electronics, vol. 30, pp. 170-171; May 1, 1957.) "Chopper-type dc amplifier uses available channels to indicate missile temperatures in an airborne telemetering system. Unit has voltage gain of 1000 with 5-v dc output and linearity within 2 per cent over the full output range. Input impedance is 100  $\Omega$  and response is flat from zero to 10 cps. Stability is within 2 per cent up to 10 g vibration at 1000 cps or over temperature range from  $-65^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ."

642.6:681.142 2878

Some of the Engineering Aspects of the Machine Translation of Language-R. E. Wall, Jr. (Commun. & Electronics, no. 27, pp. 580-584; November, 1956. Discussion, p. 585.)

621.385.833 + 537.533.72

Proceedings of the Third International Conference on Electron Microscopy, London, 1954. [Book Review]-R. Ross (ed.), Publishers: Royal Microscopical Society, London, 705 pp.; 1956. (Nature, London, vol. 179, pp. 797-798; April 20, 1957.)

#### PROPAGATION OF WAVES

621.396.11

Radio Propagation Fundamentals-K. Bullington. (Bell Sys. Tech. J., vol. 36, pp. 593-626; May, 1957.) Nomograms and graphs are included which permit numerical estimates of field strength to be made. All frequency bands of practical importance are discussed. Thirtyfour references.

Spectrum of Turbulent Fluctuations Produced by Convective Mixing of Gradients-A. D. Wheelon. (Phys. Rev., vol. 105, pp. 1706-1710; March 15, 1957.) The spectrum is calculated on the basis of the turbulent mixing of an established gradient of a passive scaler quantity (e.g., electronic density). The resulting expression is consistent with experimental results on radio wave scattering by tropospheric and ionospheric irregularities.

621,396,11 A Reflection Theory for Propagation Beyond

the Horizon-H. T. Friis, A. B., Crawford, and D. C. Hogg. (Bell Sys. Tech. J., vol. 36, pp. 627-644; May, 1957.) The atmosphere is assumed to contain fairly sharp gradients of refractive index having limited dimensions and random positions and orientations. This model gives good agreement with experimental data.

621.396.11:551.510.535

The Fading of Radio Waves Reflected from the E Layer-B. Landmark. (J. Atmos. Terr. Phys., vol. 10, pp. 288-295; 1957.) Simultaneous measurement of phase path and amplitude of waves reflected vertically from the E region are analyzed. A temporary increase in phase path was associated with an enhancement of amplitude, indicating focusing by a moving concavity in the layer.

621.396.11:551.510.535

High-Frequency Back-Scatter Observa-tions at Salisbury, South Australia—C. G. McCue. (Aust. J. Phys., vol. 9, pp. 454-470; December, 1956.) By measuring simultaneously angles of elevation and time delays of strobed back-scatter signals, seven different back-scatter modes were noted, of which the most frequent was the ground-scattered single F<sub>2</sub> hop. Transmissions directed to four characteristic types of scattering area showed that at low angles of elevation land is a more prominent source of back-scatter than sea, and that extremely larrge changes in land roughness result in increased back-scatter amplitude.

621.396.11.029.45:551.510.535

The Geometrical Optics of V.L.F. Sky-Wave Propagation-J. R. Wait and A. Murphy. (Proc. IRE, vol. 45, pp. 754-760; June, 1957.) Data are tabulated to facilitate the computation of received field strengths by combining ground and ionospheric waves. Comparison of some calculated values with experimental results leads to values of ionospheric refractive index differing from those previously published.

621.396.11.029.45:551.510.535

The Mode Theory of V.L.F. Ionospheric Propagation for Finite Ground Conductivity-J. R. Wait. (Proc. IRE, vol. 45, pp. 760-767; June, 1957.) A mathematical formulation of the theory and graphical presentation of typical conclusions. Good agreement between calculated and measured fields is shown. 621.396.11.029.45:551.510.535

2886

The Attenuation vs Frequency Characteristics of V.L.F. Radio Waves-J. R. Wait. (Proc. IRE, vol. 45, pp. 768-771; June, 1957.) Attenuation factors are presented graphically as a function of various ionospheric parameters.

621.396.11.029.45:551.510.535

The "Waveguide Mode" Theory of the Propagation of Very-Low-Frequency Radio Waves-K. G. Budden. (PROC. IRE, vol. 45, pp. 772-774; June, 1957.) Some apparent discrepancies between previous treatments are shown to be due to differences in the assumed ionospheric parameters and in the terminology for the modes.

621.396.11.029.45:551.594.6

Very-Low-Frequency Radiation from Lightning Strokes—Hill. (See 2760.)

621.396.11.029.45:621.3.018.41(083.74) Intercontinental Frequency Comparison by Very-Low-Frequency Radio Transmission— Pierce. (See 2859.)

621.396.11.029.53

The Ionospheric Attenuation of Hectometric Wave Propagation (550-1600kc/s)—M. Scholz. (Nachrichtentech. Z., vol. 10, pp. 6-11; January, 1957.) Field-strength curves for nighttime propagation in the medium-wave band obtained from various sources covering the past 22 years are compared. Other data plotted for comparison and brief discussion are the statistical distribution of field-strength variations, seasonal fluctuations, and the mean fading rate.

#### 621.396.11.029.62:523.5:621.396.67.012.12

Height-Gain in the Forward Scattering of Radio Waves by Meteor Trails-C. O. Hines and M. O'Grady. (Canad. J. Phys., vol. 35, pp. 125-127; January, 1957.) Calculated curves are presented which show the detection rate of meteors and the mean signal level for forward transmission. The quantities are given as a function of antenna height and meteor-formation height.

#### RECEPTION

621.376.2 2893

The Demodulation of Linearly Distorted A. M. Spectra-H. Schneider and G. Petrich. (Nachr-Tech., vol. 6, pp. 552-556; December, 1956.) The effect of amplitude and phase changes on the demodulating action of a receiving diode is investigated theoretically; the results are discussed with reference to the tuned selective circuit and the purely inductive hf channel.

Some Problems in the Theory of the Ratio Detector-I. Kesler. (Arch. Elektrotech., vol. 5, pp. 591-619; 1956. English summary, p. 620.) Theoretical and practical aspects of compensating amplitude variations of the input signal are discussed.

621.396.62:621.314.7

Portable Transistor Receiver-S. W. Amos. (Wireless World, vol. 63, pp. 241-246 and 340-346; May and July, 1957. Correction, ibid., p. 377; August, 1957.) A discussion of general principles of design and a stage-by-stage examination of a complete circuit, full details of which are given.

A New Approach in R.F. Front-End Design -B. B. Bycer. (Electronic Ind. Tele-Tech., vol. 16, pp. 82-84, 141; January, 1957.) The design is based on permeability tuning and the use of a triode Type 6021 as a reactance modulator for operation at 205 mc.

621.396.812.3 2897

The Effect of the Recorder Time on the Apparent Speed of Fading of a Radio Signal-S. A. Bowhill. (J. Atmos. Terr. Phys., vol. 10, pp. 338-339; 1957.)

621.396.822:551.594.6

2898

Noise Investigation at V.L.F. by the National Bureau of Standards-Crichlow. (See

621.396.822:551.594.6

2899

Some Recent Measurements of Atmospheric Noise in Canada-McKerrow. (See 2762.)

621.396.822:551.594.6

2900

Characteristics of Atmospheric Noise from 1 to 100 kc/s—A. D. Watt and E. L. Maxwell. (See 2763.)

621.396.823:537.523.3

2901 The Radio Interference Produced by

Corona Discharge-M. I. Large. (J. Atmos. Terr. Phys., vol. 10, pp. 245-250; 1957.) The spectrum of interference observed on a receiver showed peaks of noise at harmonics of the corona pulse repetition frequency, these noise peaks merging above the tenth harmonic. The spectrum conforms to that expected for pulses of variable interval.

621.396.823:537.523.3 2902 A Relaxation Oscillation Maintained by Discharge Corona-M. I. Large. (Nature, London, vol. 179, pp. 707-708; April 6, 1957.) During an investigation of interference due to negative corona from a receiver antenna (2901 above), a fine wire point a few millimeters from a plane at high potential was observed to oscillate, producing in a receiver a musical tone at twice the frequency of mechanical oscillation.

#### STATIONS AND COMMUNICATION SYSTEMS

621.376.3/.4:621.396.822

Power Spectrum of a Carrier Modulated in Phase or Frequency by White Noise-R. Hamer and R. A. Acton. (Electronic Radio Eng., vol. 34, pp. 246-253; July, 1957.) "Measurement of the power spectrum of a carrier, modulated either in phase or in frequency by a uniform Gaussian noise signal, is described, and the results are interpreted in the light of existing theory. A combination of measured and theoretical results is used to prepare generalized curves of fm and phm noise spectra.'

621.30.001.11 2004

Instantaneous Companding of Quantized Signals-B. Smith. (Bell Sys. Tech. J., vol. 36, pp. 653-709; May, 1957.) An extension of the analysis of Panter and Dite (1488 of 1951) permits the calculation of the quantizing error power as a function of a number of parameters. These calculations lead to the proper combination of the number of digits per code group and companding characteristic for quantized speech communication systems. Theoretical and experimental studies are compared.

621.39.001.11

Geometric Interpretation of some Results Channel Capacity Calculations-C. E. Shannon. (Nachrichtentech. Z., vol. 10, pp. 1-4; January, 1957.) Translated and amplified version of an English paper published in Nachrichtentech. Fachberichte, vol. 6, pp. 13-15; 1957. The capacity of discrete channels not containing memory devices is investigated.

621.396.2:551.510.52

Communications Potentialities of Tropospheric Scatter-M. Telford, (Point to Point Telecommun., vol. 1, pp. 29-52; February, 1957.) The calculation of received signal level is discussed and charts are given. FM, ssb, and diversity systems are considered together with an apraisal of the possibilities in relaying television.

621.396.4 2907

Introduction to Channelling Systems on H.F. Radio Circuits-A. W. Cole. (Point to Point Telecommun., vol. 1, pp. 5-12; February, 1957.) The history and trends of development in frequency-division and time-division channeling are briefly reviewed as an introduction to later articles.

621.396.4:621.396.72.029.62

Radio-System Surveying on Very High Frequencies-D. C. H. Mellon. (Point to

Point Telecommun., vol. 1, pp. 13-27; February, 1957.) Factors governing the choice of sites for multichannel vhf systems are considered, and site testing is discussed.

621.396.41:621.396.72

Experience with Single-Sideband Mobile Equipment—R. Richardson, O. Eness, and R. Dronsuth. (PRoc. IRE, vol. 45, pp. 823-829; June, 1957.) The performance of the equipment, designed to operate at 159 mc, is compared with that of narrow-band fm equipment.

621.396.61/.62:621.314.7:621.311.6 Transistor Equipment using Freely Available Power Supplies—(See 2916.)

621.396.65.029.64

2011

The Use of the Lower Centimetric Wavelengths for Radio Communication—G. Megla. (Hochfreg. und Elektroak., vol. 64, pp. 194-199; May, 1956.) An examination of the microwave absorption by atmospheric gases and precipitation indicates that attenuation is sufficiently low for radio links at wavelengths down to 2 cm. Systems operating at 4 cm λ over a 33-km path using various forms of guided transmission are compared with a freespace transmission system; the latter has great economic advantages.

#### SUBSIDIARY APPARATUS

621-526

An Introduction to the Study of Nonlinear Control Systems—J. F. Coales. (J. Sci. Instr., vol. 34, pp. 41–47; February, 1957.) The nonlinearities may be used to improve the system performance provided they occur in the forward loop outside the load and are instantaneous; i.e., there is no applicable delay between input changes and output response.

Activation of Electrical Contacts by Organic Vapours-L. H. Germer and J. L. Smith. (Bell Sys. Tech. J., vol. 36, pp. 769-812; May, 1957.) Carbon from the decomposed vapors may make it impossible to protect contacts against arcing by conventional RC networks. The activation process is discussed.

621.3.078:621.316.825:621.383

A Thermistor Device as Automatic Gain Control in Lamp-Photocell Transducer Systems -A. M. Hardie. (J. Sci. Instr., vol. 34, pp. 58-62; February, 1957.) Stabilization to within 0.03 per cent is achieved if the light beam is modulated symmetrically.

621.311.6:621-526.001.4

Power Amplifier for Servo Testing-J. M. Diamond. (Electronics, vol. 30, pp. 176-177; May 1, 1957.) A cathode follower supplies 90w at 400-2600 cps.

621.311.6:621.396.61/.62:621.314.7 Transistor Equipment using Freely Available Power Supplies-H. E. Hollmann. (Hochfreg. und Elektroak., vol. 64, pp. 168-180; May, 1956.) The equipment described includes portable transmitters and receivers drawing power from solar batteries, hand-driven dynamos, sound energy, and the rf energy of a local broadcasting transmitter. See also 1893 of

621.311.69:537.311.33:535.215

Photoelectric Converters of Solar Energy of p-Type Silicon—Yu. P. Maslakovets, S. A. Poltinnikov, G. B. Dubrovski, and V. K. Subashiev. (Zh. Tekh. Fiz., vol. 26, pp. 2396– 2397; October, 1956.) Brief note on experimental results. Efficiencies up to 2.8 per cent were obtained.

621.311.69:621.362

Conversion of Radiations into Electricity V. B. Veinberg and Yu. V. Mal'tsev. (Zh. Tekh., Fiz., vol. 26, pp. 2373-2377; October, 1956.) Calculation of the efficiency of converting solar radiation into electrical energy via a heat engine. Numerical data are tabulated for various heater systems; efficiencies 3-4 times greater than those of thermoelectric converters are indicated.

621.314.6+621.316.72

The Valve in Power Supply Units-K. Steimel. (Telefunkenröhre, no. 34, pp. 1-246; December, 1956.) The problems of stability and stabilization in electronic voltage and current supplies are discussed in detail. A section deals with rectification as a function of different circuit characteristics; other chapters describe and compare numerous basic tube circuits

used for various stabilizing purposes including special applications of more elaborate circuitry.

## TELEVISION AND PHOTOTELEGRAPHY 621.397.5 2920

Horizontal versus Vertical Resolution—L. C. Jesty. (Wireless World, vol. 63, pp. 304-306; July, 1957.) No data appear to be available which suggest that greater sharpness is desirable in one direction rather than any other. The vertical/horizontal resolution is discussed; the number of lines should be increased beyond 405 to achieve equal resolution in these two directions.

#### 621.397.5:389.6

The Results of the 8th General Assembly [of the C.C.I.R.] (Warsaw 1956) in the Field of Black-and-White Television—J. Müller. (Nachrichtentech. Z., vol. 10, pp. 27-30; January, 1957.)

#### 621.397.5:535.623

The Information Content and Frequency Bandwidth of the Chrominance Signal in a Subcarrier System of Colour Television—P. Neidhart. (*Nachr-Tech.*, vol. 6, pp. 529–533; December, 1956.) Problems arising from the adaption of the NTSC system to the 625-line standard are considered.

#### 621.397.5:535.623

The Efforts of the C.C.I.R. concerning a European Standard for Colour Television—F. Kirschstein, J. Müller, and K. O. Schmidt. (Nachrichtentech. Z, vol. 10, pp. 1-4; January, 1957.) Report on the discussions of a CCIR study group and on its visit to the U.S.A., France, Great Britain, and the Netherlands.

#### 621.397.5:535.623 2924

Colour TV in U.S.A.—C. G. Mayer. (Wireless World, vol. 63, p. 325; July, 1927.) A favorable review of the status of color television with respect to that of black-and-white, implies that there is no longer any basis for the "color-blindness" which seems to prevail in Britain today.

#### 621.397.6.001.4:535.623

Simultaneous Colour-TV Test Signal—R. C. Kennedy. (Electronics, vol. 30, pp. 146–149; May 1, 1957.) Differential gain, phase characteristic, flag-burst, and chroma amplitudes of monitor or receiver can be determined using a test signal transmitted simultaneously with the program. The signal occupies three horizontal lines, one line displaced above top of picture.

#### 621.397.611.2

Transmission Defects of the Image Orthicon Television Camera Tube—R. Theile and F. Pilz. (Arch. elekt. Übertragung, vol. 11, pp. 17–32; January, 1957.) The causes are investigated of the characteristic spurious signals originating in this type of tube which give rise to picture distortion and loss of definition. These defects are due to capacitive coupling between adjacent picture elements and the deflection of scanning electrons by the potential pattern of the stored charge. Modifications of the construction and operation of the tube are suggested.

#### 621.397.62:535.8

A New Optical Viewfinder for Television Cameras—P. Lindner and E. Kosche. (Nachr-Tech., vol. 6, pp. 538-544; December, 1956.) Description of optical view-finder in which correctness of focusing is indicated over the whole image. Its advantages over electronic view-finders are evident from a point-by-point comparison.

#### 621.397.62:621.374.33

Noise Gating Tube for A.G.C. and Sync— J. G. Spracklen, W. J. Stroh, and G. C. Wood. (Electronics, vol. 30, pp. 172-175; May 1, 1957.) "Single miniature tube performs entire functions of sync clipping, generating agc voltage and giving high degree of noise immunity to both these sections of a television receiver. Type 6BU8 contains common cathode, grid, and screen with separate plates and no. 3 grids."

#### 621.397.621:778

Construction of Equipment for the Photography of Single Frames of Television Pictures — K. Kröner. (*Elektronik*, vol. 6, pp. 12-15; January, 1957.) The equipment described is based on the circuit of Dillenburger and Wolf (586 of 1956).

#### 621.397.621.2:535.623 2930

The Choice of Colour Phosphors and the Occurrence of Colour Information Losses—I. Bornemann. (Nachr-Tech., vol. 6, pp. 534-537; December, 1956.) The requirements governing the choice of phosphors for use in tricolor cr tubes are discussed. The use of the Valensi diagram for determining information losses is proposed.

#### 621.397.74(44) 293

The French Television Network—Leschi. (Télé. Franc., no. 138, pp. 9-22; January, 1957.) Outline of the development planned by the RTF with lists of stations and maps showing their coverage; details of the individual transmitters are also given.

#### TUBES AND THERMIONICS

#### 621.314.63 + 621.314.7 293

The High Current Limit for Semiconductor Junction Devices—N. H. Fletcher. (PROC. IRE, vol. 45, pp. 862–872; June, 1957.) At very high current densities new formulas must be derived considering previously neglected effects. Predictions of the theory for particular devices are in good agreement with experiment and show how the available parameters should be varied to achieve specific results.

#### 621.314.63 293

The Forward Voltage/Current Characteristics of a Junction-Type Rectifier for Large Currents—E. I. Rashba and K. B. Tolpygo. (2h. Tekh. Fiz., vol. 26, pp. 1419–1427; July, 1956.) A theoretical discussion is presented, in which an equation is derived for the voltage/current characteristic of a p-n junction-type diode of arbitrary thickness for large currents, on the assumption that the barrier layer is flooded with carriers and that the main voltage drop occurs in the bulk of the semiconductor. A numerical example showing the application of the equation to a germanium diode is included, and the accuracy of the method proposed is estimated.

#### 621.314.63:537.311.33

Theory of the Metal/Semiconductor Contact—S. U. Umarov and L. G. Gurvich. (Zh. Tekh. Fiz., vol. 26, pp. 2179–2184; October, 1956.) A calculation of the current/voltage characteristics is presented, taking into account the current across the junction and the degree of ionization of the impurity centers. The calculation is approximate and does not take account of the influence of the change of the average kinetic energy of the electron gas under the influence of the electric field.

#### 621.314.63:546.28:539.18

Effects of Irradiation upon Diodes of the Silicon Junction Type—R. Gorton. (Nature, London, vol. 179, p. 864; April 27, 1957.) After irradiation by slow and fast neutrons, a progressive change in the forward characteristics occurred accompanied by a distinct reduction of minority-carrier storage. There was no significant change in the reverse characteristics.

#### 621.314.63:546.289

Measurements of Current as a Function of Temperature in Germanium n-p Junctions—H. Bernard. (J. Electronics, vol. 2, pp. 579-596;

May, 1957. In French.) Measurements of reverse current in grown Ge p-n junctions at temperatures above  $10^{\circ}\text{C}$  agree well with Shockley's theory. Below  $10^{\circ}\text{C}$  the reverse current arises from electron-hole generation in the space-charge layer. This mechanism is also used to explain the forward current characteristics measured between  $-50^{\circ}\text{C}$  and liquid-nitrogen temperatures.

#### 621.314.63:546.289

Some Properties of Diodes of Germanium with Gold Admixture—A. A. Lebedev, V. I. Stafeev, and V. M. Tuchkevich. (Zh. Tekh. Fiz., vol. 26, pp. 2131–2141; October, 1956.) An exerimental investigation of the I/V and breakdown-voltage characteristics at temperatures down to  $78^{\circ}$ K is reported.

#### 621.314.63+621.314.7]:621.396.822

Theory and Experiments on Shot Noise in Semiconductor Junction Diodes and Transistors—W. Guggenbühl and M. J. O. Strutt. (Proc. IRE, vol. 45, pp. 839-854; June, 1957.) A general theory of shot noise, for low-current densities, and its dependence on frequency in the If and hf bands. Experimental results at low-level injection agree well with the theory, but some deviation is apparent at high levels.

#### 621.314.63.012.8

Theoretical Consideration of the Physical Basis for the Equivalent Circuit of Semiconductor Diodes at High Current Densities—W. Guggenbühl. (Arch. elekt. Übertragung, vol. 10, pp. 483–485; November, 1956.) Consideration of the transient response of junction diodes in the high-current region is based on Herlet's theory of their dc performance (Z. Naturf., vol. 11a, pp. 498–510; June, 1956). This accounts for the inductive part of the ac characteristics of a p-n-junction diode at high-injection levels. Experimental results agree satisfactorily with theory.

#### 621.314.7

Transistor Circuit Symbols—E. H. Cooke-Yarborough. (Wireless World, vol. 63, pp. 333–334; July, 1957.) The need to use symbols which distinguish between point-contact and junction transistors (1942 of 1957) is emphasized, together with the need for keeping to the "negative down" polarity convention already established with tube circuits.

#### 621.314.7:621.374.32:681.142

Computer Switching with Micro-alloy Transistors—Angell and Fortini. (See 2686.)

#### 621.314.7:621.375.4

Transistor Operating-Point Stabilization—A. Cramwinckel. (*Philips Telecommun. Rev.*, vol. 17, pp. 100–107; January, 1957.) A method of stabilizing transistors against increased collector leakage current caused by a rise in temperature. A dc negative-feedback method is described which is effective up to about 80°C for Ge transistors.

#### 621.314.7:621.375.4.029.5/.6

Transistors in High-Frequency Amplifiers—W. Guggenbühl and M. J. O. Strutt. (*Electronic Radio Eng.*, vol. 34, pp. 258–267; July, 1957.) A discussion of the frequency dependence of transistor parameters is followed by a review of the qualities of hf transistors and of the various problems which arise in their use. Twenty-nine references.

#### 621.314.7:621.396.822

2935

Abnormal Noise in Junction Transistors during Secondary Ionization—R. B. Jackson and A. K. Walton. (Proc. Phys. Soc., London, vol. 70, p. 251; February 1, 1957.)

## 621.314.7.002.2

The Depth of Diffused Layers—W. L. Bond. (Bell Lab. Rec., vol. 35, pp. 1-5; January, 1957.) An interference fringe technique is described for measuring the depth of con-

ductivity layers diffused into semiconductor crystals in transistor fabrication.

621.383.2 2946

On the Constancy of the Spectral Characteristics of Oxygen-Caesium and Antimony-Caesium Vacuum Photocells—V. S. Khazanov and S. G. Yurov. (Zh. Tekh. Fiz., vol. 26, pp. 1170–1173; June, 1956.) The effect of the magnitude of the applied voltage on the spectral sensitivity of the photocell was investigated experimentally. The data so obtained are compared with those of other authors.

621.383.2 2947

The Energy Distribution of Photoelectrons in the External Photoeffect of the Antimony-Caesium Cathode—Yu. K. Shalabutov and N. S. Maslennikova. (Zh. Tekh. Fiz., vol. 26, pp. 1166–1169; June, 1956.) Measurements of spectral response and energy distribution of photoelectrons are reported. The (dN/dE)/E curves, where E is the energy, show maxima near 0.6 and 0.2 ev for photoelectrons liberated by 530-m $\mu$  irradiation.

621.383.27 294

Fluctuations in Photomultipliers and Statistical Properties of Secondary Emission—P. Moatti. (C.R. Acad. Sci., Paris, vol. 244, pp. 1742–1744; March 25, 1957.) Statistical treatment to determine the number of electrons comprising an output pulse when emission is initiated by 1) a single electron, 2) a group of electrons with Poisson distribution.

621.383.27 2949

Synchronization Accuracy Obtainable with Multiplier Phototubes—L. Levi. (Commun. & Electronics, no. 27, pp. 603–606; November, 1956.) The jitter in photomultiplier synchronization systems is analyzed to determine the effect of bandwidth, type of photocell, and optical parameters.

621.383.4 2950

A New Photocell for Long-Wave Infrared Radiation—E. Suchel. (Elektronische Rundschau, vol. 10, pp. 296–298; November, 1956.) The characteristics of the PbS cell Type 61SV for use in the wavelength range  $0.3-3.5~\mu$  are given; its sensitivity is greatest at  $2.5~\mu$ . Some typical applications are indicated.

621.383.42 2951

Influence of Temperature on the Height of the Potential Barrier of Selenium Photocells—G. Blet. (C.R. Acad. Sci., Paris, vol. 244, pp. 1754–1756; March 25, 1957.) The barrier potential determined from measurements of the emf of a cell in vacuum is independent of temperature in the range 125°–300°K

621.383.5:546.23:621.396.822 2952

Flicker Effect in Selenium Photovoltaic Cells—M. Téboul and N. Nifontoff. (C.R. Acad. Sci., Paris, vol. 244, pp. 1631–1633; March 18, 1957.) To a first approximation the flicker effect does not appear to be influenced by the illumination of the cell when the voltage across the rectifying contact is held constant.

621.383.5:546.817.221

A Single-Crystal Photodiode of Lead Sulphide—J. Starkiewicz, G. Bate, H. Bennett, and C. Hilsum. (*Proc. Phys. Soc., London*, vol. 70, pp. 258–259; February 1, 1957.) A photovoltaic cell with a time constant <1µs.

621.385:621.396.822 2954

An Investigation into the Flicker Effect—A. M. Malakhov and V. E. Dubrovin. (Zh. Tekh. Fiz., vol. 26, pp. 1451–1455; July, 1956.) The flicker voltage developed across a resistance in the anode circuit of the tubes was measured over a frequency range from 0.5 to 120 cps, and the spectral density of the fluctuations was determined. The dependence of the intensity of the flicker effect and the form of its spectrum on the operating conditions of the tube, and, in particular, on residual gas in the tube

are briefly discussed. A theoretical interpretation of the results obtained is given.

621.385.001.4:534.1

White-Noise Vibration Test for Electron Tubes—J. D. Robbins. (Sylvania Technologist, vol. 10, pp. 10-12; January, 1957.)

621.385.004.2

The Effects of Overload and Operation at High Altitudes on Electron-Tube Life—H. C. Pleak and A. V. Baldwin. (Sylvania Technologist, vol. 10, pp. 2-4; January, 1957.)

621,385.029.6

Interchannel Interference due to Klystron Pulling—H. E. Curtis and S. O. Rice. (Bell Sys. Tech. J., vol. 36, pp. 645-652; May, 1957.) Expressions are derived for the magnitude of the interference when the speech load is simulated by random noise.

621.385.029.6 2958

The Measurement of Space-Charge Wavelength in an Electron Beam—D. Walsh. (*J. Electronics*, vol. 2, pp. 436-440; March, 1957.) "A method is described of measuring the wavelength of space-charge waves in an electron beam by comparing the klystron gain between cavities unequally spaced along the beam."

621.385.029.6

On Space-Charge Waves—R. H. C. Newton. (J. Electronics, vol. 2, pp. 441–449; March, 1957.) The wave equation for an electron beam in a collimating magnetic field is derived. The analysis is applicable when there is no positive space charge and is not entirely restricted to small-signal conditions.

621.385.029.6 2960

High-Order Space-Charge Waves in Klystrons—A. H. W. Beck. (J. Electronics, vol. 2, pp. 489-509; March, 1957.) Theoretical expressions are obtained for cylindrical and annular beams focused with an infinite magnetic field. The calculations are simplified by the use of finite Hankel transforms. Beams in finite magnetic fields are closely similar provided that the focusing field is somewhat greater than the Brillouin field for the same current, voltage, and beam diameter.

621.385.029.6 2961

Space-Charge Waves along Magnetically Focused Electron Beams—J. Labus. (Proc. IRE, vol. 45, pp. 854–861; June, 1957.) Two procedures in the analysis of wave propagation along electron beams are compared by consideration of different displacements of the beam surface.

621.385.029.6 296

Space Harmonics in Electron Streams—R. Müller. (Arch. elekt. Übertragung, vol. 10, pp. 505–511; December, 1956.) The formation is considered of space-charge waves in electron beams traveling along specially shaped paths or under periodically changing dc conditions. The application of this phenomenon for generating high-harmonic frequencies is briefly discussed.

621.385.029.6

On the Spreading of Bunches of a Space Charge—O. P. Beguchev. (Zh. Tekh. Fiz., vol. 26, pp. 1483–1486; July, 1956.) A rigorous mathematical description is given of the process of the spreading of bunches of an uncompensated space charge.

621.385.029.6

On the Space Charge Affected by the Magnetic Field: Part 2—Y. Yasuoka. (J. Phys. Soc. Japan, vol. 11, pp. 1292–1295; December, 1956.) A more advanced treatment of Part 1 (2575 of 1956) taking into account the effect of the magnetic field on the scattered electrons. Better agreement is obtained with experimental values.

621.385.029.6

On the Shape of Electron Trajectories in a Magnetron under Static Conditions—B. Ya. Moizhes. (Zh. Tekh. Fiz., vol. 26, pp. 1836-1840; August, 1956.) The equation of motion of electrons in a cylindrical magnetron, with an anode-radius/cathode-radius ratio approaching unity is derived taking into account the space charge, and trajectories in magnetic fields exceeding the critical vaue are considered.

621.385.029.6 2966

Minimum Noise Coefficient of Double-Stream Valve—S. K. Lesota. (Radiotekhnika i Electronika, vol. 1, pp. 1288–1291; September, 1956.) The calculation presented takes into account the correlation of fluctuations of the current and voltage in the double electron stream. A linear approximation and lossless-multipole theory are used. Results show that the minimum noise coefficient is higher for the double-stream tube than for a traveling-wave tube operating under similar conditions for fluctuations in the potential minimum.

621.385.029.6 2967

Theory of Nonlinear Phenomena in Travelling-Wave Amplifiers—A. A. Vedencv. (Radiotekhnika i Elektronika, vol. 1, pp. 1377–1378; October, 1956.) The limitation of the increase in amplitude is deduced from general energy relations without recourse to a concrete model.

621.385.029.6

Developments of the Strophotron—H. Höggblom and S. Tomner. (Ericsson Tech., vol. 12, pp. 165–184; 1956.) This transit-time tube was originally described by Alfven and Romell (3398 of 1954). Experimental results are reported for different types including the coaxial strophotron and the simplified theory is outlined. Oscillator efficiencies of 30 per cent at 1000 mc and 10 per cent at 5000 mc have been achieved.

621.385.029.6:621.375.2:621.396.65 2969

Design Considerations for Output Stages, Travelling-Wave Valves in Radio-Link Equipment—M. Müller. (Nachrichtentech. Z., vol. 10, pp. 11–15; January, 1957.) On the basis of theoretical considerations traveling-wave tube operating and design data are tabulated for mid-band frequencies of 2, 4, 6, and 10 kmc and outputs of about 1 to 200 w for a focusing field of 600 g.

621.385.029.63/.64 2970

A Study of the Broad-Band Frequency Response of the Multicavity Klystron Amplifier—K. H. Kreuchen, B. A. Auld, and N. E. Dixon. (J. Electronics, vol. 2, pp. 529–567; May, 1957.) "A theoretical method is described for the evaluation of the amplitude-frequency response of a stagger-tuned klystron amplifier. The practical verification of the theoretically predicted response was carried out on a demountable four-cavity S-band klystron amplifier."

621.385.029.63/.64:621.317.755 2971 The Wamoscope—a Microwave Display Device—George. (See 2870.)

Device—George. (See 2070.)

621.385.029.63/.64:621.317.755:621.385.833 2972

Typical Applications of the Wamoscope— H. Briskin. (Sylvania Technologist, vol. 10, pp.

8-9; January 1957.) A radar receiver and microwave televeision receiver are discussed.

621.385.029.63/.64:621.376.3

Voltage-Tuned Magnetron for F. M. Applications—T. R. Bristol and G. J. Griffin, Jr. (Electronics, vol. 30, pp. 162–163; May 1, 1957.) "Stacked metal-ceramic miniature magnetron operating in 2-kmc to 4-kmc range has average output power capabilities up to 10 w. Effects of operation in tapered S-band wave-

guide and ridged waveguide are given and normal operating characteristics, together with present and future applications, are discussed.

621.385.029.64

Backward-Wave Oscillators for the 17- to 41-k Mc/s Band-J. A. Noland and R. E. Lepic. (Sylvania Technologist, vol. 10, pp. 13-16; January, 1957.) Two backward-wave oscillators for use as local oscillators are described; the frequency ranges covered are 17-27 kmc and 26.5-41 kmc.

621.385.032.2

High-Perveance Electron Guns-R. Hechtel. (Arch. elekt. Übertragung, vol. 10, pp. 535-540; December, 1956.) Various methods of obtaining high perveance are outlined. Pierce's formula for calculating perveance was amplified to cover higher values and applied to a gun having a perveance of  $5\mu A/V^{3/2}$ ; the calculated results were verified experimentally.

621.385.032.2:539.23:537.533.9

The Electron Bombardment of Thin Barium Films—L. Jacob. (Proc. Phys. Soc., London, vol. 70, pp. 235–239; February 1, 1957.) Describes how barium is deposited as a thin film on a strontium oxide cathode by electron bombardment.

621.385.032.213

Evaporation of Barium from Impregnated Cathodes-I. Brodie and R. O. Jenkins. (J. Electronics, vol. 2, pp. 457-476; March, 1957.) For cathodes impregnated with barium aluminate, the evaporation of barium increases rapidly when the barium-oxide/alumina molar ratio exceeds 3. The addition of calcium oxide inhibits the rate of evaporation.

621.385.032.213

Studies on the Mechanism of Operation of the L Cathode: Part 1-E. S. Rittner, R. H. Ahlert, and W. C. Rutledge. (J. Appl. Phys., vol. 28, pp. 156-167; February, 1957.) The emission, evaporation rate, evaporant composition, and constitution of the emitting surface were examined. Activation of the tungsten plug comes from strongly adsorbed BaO issuing from the pores. The active surface consists of a nearly complete oxygen monolayer covered by a complete barium monolayer. The emission approaches the maximum possible for a bariumactivated tungsten dispenser cathode.

621.385.032.213

Studies on the Mechanism of Operation of the L Cathode: Part 2-W. C. Rutledge and E. S. Rittner. (J. Appl. Phys., vol. 28, pp. 167-173; February, 1957.) An experimental study including the chemistry of carbonate decomposition and barium generation, the origin of BaO in the evaporant, the barium transport mechanism through the porous plug, and the factors determining cathode life.

621.385.032.216

Application of a Mass Spectrometer in an Investigation of the Process of Activation of an Oxide Cathode-N. D. Morgulis and G. Ya. Pikus. (Zh. Tekh. Fiz., vol. 26, pp. 1174-1176; June, 1956.) A study of the activation processes by gas analysis is reported.

621.385.032.216:537.582:537.543.2

An Investigation into the Distribution of the Work Function over the Surface of an Oxide Cathode-D. G. Bulyginski and L. N. Dobretsov. (Zh. Tekh. Fiz., vol. 26, pp. 1141-1149; June, 1956.) A method is proposed for measuring the distribution of the work function in the case of heterogeneous cathodes, and a detailed report is presented on these measurements for various states of activation of an oxide cathode. The data obtained are sufficient for giving a quantitative indication of the maximum and minimum values of the work functions, their variation with temperature, etc. The local work functions have a positive temperature coefficient, the value of which is higher, the greater the work function itself.

The Cylindrical Diode-D. A. Bell and H. O. Berktay. (J. Electronics, vol. 2, pp. 425-435; March, 1957.) The following features of the cylindrical thermionic diode are reviewed: 1) current density, with and without allowance for initial electron velocities, 2) the retardingfield characteristic, 3) shot noise under spacecharge controlled conditions.

621.385.2

Thermal Fluctuations in Space-Charge-Controlled Diodes—D. A. Bell. (J. Electronics, vol. 2, pp. 477-488; March, 1957.) If, in the analysis, the conservation of energy is taken into account when compounding the thermal and drift velocities of electrons in transit, then larger fluctuations are predicted than if thermal and drift velocities are linearly superimposed. For both planar and cylindrical diodes the former treatment is more nearly in accord with experimental observations.

621.385.2

Initial Current Establishing Processes in a Planar Diode with an External Magnetic Field -Yu. V. Pimenov. (Zh. Tekh. Fiz., vol. 26, pp. 1955-1965; September, 1956.) The initial build-up of current, under space-charge limit conditions, following the application of a pulse voltage to the anode, is considered theoretically.

621.385.3:621.373.4

The Stability of Oscillations of a Triode-L. Sidériades. (Onde élect., vol. 37, pp. 48-54; January, 1957.) The analysis outlined is based on the topological method applied to an equivalent dynamic system. By means of isoclines the cyclic limits of stable oscillation are found. Experimental verification is provided by the integral curves obtained on a cr tube screen.

621.385.3:621.373.421.14

The High-Power Long-Pulse Triode Type TH470 and Associated Circuits-(Rev. Tech. Comp. Franç. Thomson-Houston, no. 24, pp. 9-29; December, 1956.)

Part 1-Special Problems of High-Frequency Pulse Generators Used in Particle Accelerators—E. P. Courtillot (pp. 11-12)

Part 2-Investigation of Valve Type TH470 -J. Péhé (pp. 13-20).

Part 3-2-MW Peak Pulse Generator-J. Afanassieff (pp. 21-29).

621.385.3:621.373.421.14

The Triode Type TH1500 M2-M. Descarsin. (Rev. Tech. Comp. Franç. Thomson-Houston, no. 24, pp. 31-39; December, 1956.) The tube described is used in 100- or 200-mc radar pulse generators.

621.385.4:546.817.221:621.396.822

Investigation of the Noise of Lead Sulphide Photoresistors-A. I. Goryachev and K. A. Yumatov. (Radiotekhnika i Elektronika, vol. 1, pp. 1503-1514; December, 1956.) Results are presented of an experimental investigation of the dependence of noise on operational conditions and on the dimensions of the photoresistors. The results are tabulated and presented graphically.

Systems with Centrifugal Electrostatic Focusing of the Electron Beam-Z. S. Chernov. (Radiotekhnika i Elektronika, vol. 1, pp. 1428-1434; November, 1956.)

Errors of Magnetic Deflection: Part 1-J. Haantjes and G. J. Lubben. (Philips Res. Rep., vol. 12, pp. 46-68; February, 1957.) A detailed analysis of the deflection errors in cr tubes. With the exception of those due to curvature of the image field, most errors can be reduced by suitable distribution of the deflecting field.

621.385.832

Viewing Storage Tubes for Large Displays -H. O. Hook, M. Knoll, and R. P. Stone. (RCA) Rev., vol. 17, pp. 503-514; December, 1956.) Two experimental tubes are described. One provides a 10-inch-diameter display for direct viewing with 250 foot-lamberts highlight brightness; the second is a projection tube with a 41-inch spherical luminescent screen providing more than 5000 foot-lamberts brightness. Resolution is better than 500 lines. For an earlier 4-inch half-tone viewing storage tube, see 308 of 1955 (Knoll, et al.).

621.385.832:621.397.6

Calculation of Resolving Power of an Electron-Optical [image] Converter with Uniform Fields-B. E. Bonshtedt, T. G. Dmitrieva, and I. I. Tsakkerman, (Zh. Tekh, Fiz., vol. 26, pp. 1966–1968; September, 1956.) Criticism of an assumption made by DeVore (2385 of 1948) and Wendt (1918 of 1956) in deriving an expression for the resolving power.

621.385.833.032.2

A Contribution on the Triode System of the Cathode-Ray-Tube Electron Gun-M. Haine. (J. Brit. IRE, vol. 17, pp. 211-216; April, 1957.) An analysis of published experimental data suggests the system suffers from severe spherical aberration, arising from the field close to the cathode. If this limitation were overcome, a reduction in beam diameter and cathode loading would be possible.

621.387:621.318.57

Cold-Cathode Gas Tubes for Telephone Switching Systems-M. A. Townsend. (Bell Sys. Tech. J., vol. 36, pp. 755-768; May, 1957.)

#### MISCELLANEOUS

001.891:621.396(54)

Programme for Radio Research in India-(J. Sci. Indus. Res., vol. 15A, pp. 550-552; December, 1956.) Outline of a 5-year program drawn up on behalf of the Council of Scientific and Industrial Research, India.

061.4 Instruments Electronics Automation Exhi-

bition, 1957-Review of Equipment-(Instr. Practice, vol. 11, pp. 631-656; June, 1957.)

Report of the Max Planck Society for the Advancement of Science, for the Period 1st April 1954 to 31st March 1936-Naturwiss., vol. 43, pp. 545-580; December, 1956.) Summaries of the activities of the Institute for Ionospheric Research and of the Computer Group are included.

558.569.2.047 Maximum Permissible Radiation Exposures to Man-(Tech. News Bull. Nat. Bur.

Stand., vol. 41, pp. 17-19; February, 1957.) A preliminary statement of the U. S. National Committee on Radiation Protection and Measurement on new safe limits. The recommendations on protection against betatron-synchrotron radiations up to 100 mev are published in National Bureau of Standards Handbook H55. A list of other handbooks is appended.

621.3.049.75

Testing of Foil-Clad Laminates for Printed Circuitry-T. D. Schlabach, E. E. Wright, A. P. Broyer, and D. K. Rider. (ASTM Bull., no. 222, pp. 25-30; May, 1957.) Methods of testing insulation resistance, peel strength, solder-dip resistance, water absorption, volume, and surface resistivity by means of specially designed test specimens are described and discussed. An arrangement of these specimens forming a composite test pattern has been developed for etching foil-clad laminates so that the various parameters can be tested on a given



TECHNICAL DATA MOTOROLA MN19						
M	Maximum Ratings Typical Values				ues	
	V <sub>CB</sub>	VCE	fαb	h <sub>FE</sub>	Vcs	
Test Condition	Emitter Open	Base Open	$I_C = 3 \text{ ma}$ $V_{CB} = 5 \text{V}$ .	$I_{\rm C}=10$ ma $V_{\rm CE}=1V.$	$I_C = 10 \text{ ma}$ $I_B = 1 \text{ ma}$	
Value	40V.	20V.	8 MC	40	.05V.	

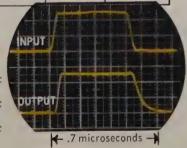
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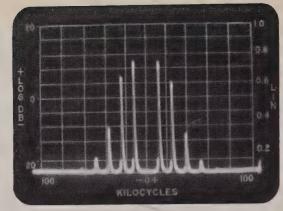


High-Voltage Power Transistors





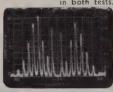
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display shows actual
sideband spread including those beyond deviation.



## FM problem

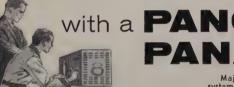
pictures like these give the answers you need for FM operating and equipment testing





10 kc modulation at second carrier flue

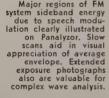
Same modulation level-frequency

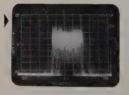




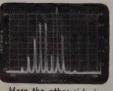
#### you can

- Determine sideband spillover . . . assure conformance with statutory bandwidth restrictions of sideband energy
- Measure deviation precisely through carrier and sideband nulls
- See RAPIDLY the frequency vs amplitude contents of FM signals . 1. compare relative magnitudes of FM frequency components
- · Observe clearly sideband structure under complex forms of modulation
- Analyze carrier shifts, incidental AM. hum, RF harmonics non-linearities . . . detect carrier pulling or instability in both magnitude and direction
- Adjust operating parameters at optimum.



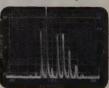


Two photos showing FM due to clipped sine waves.



Relative lack of sidebands to left of carrier (centered on Panalyzor screen) indicate limited deviation on clipped end of oscillator swing

Here the other side is clipped. Note mirror image effect and slight carrier shift.



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(Continued from page 88A)

#### Stabilized Toroids



The United Transformer Corp., 150 Varick St., New York 13, N. Y., announces a new series of extremely stabilized toroid coils for high frequency application. Temperature stabilization covers the range from -40° C to +85° C. This MQD series consists of six different types ranging from 2 millihenry to 20 millihenry inductance. The Q is 170 at 50 kc, ranging down to approximately 80 at 12 kc and 130 kc (slightly lower for higher inductances). These MQD units are hermetically sealed to MIL-T-27A specifications (MIL type TF4RX20YY). Their dimensions are  $\frac{11}{16} \times 1\frac{9}{32} \times 1\frac{23}{32}$  inches with a weight of 4 ounces.

#### Clipper Diode Rectifier

Electronic Enterprises Inc., 65-67 Seventh Ave., Newark 4, N. J., manufacturer of special purpose vacuum tubes and piezo electric devices, announces the addition of a new tube type to their line.

The EE576A is a high vacuum clipper diode-rectifier, which meets all of its maximum ratings with a safety margin, particularly heat dissipation. Rectifier ratings (maximum): filament voltage 5.0 vac; filament current 14.0 amperes, peak inverse volt 25,000 volts, peak plate current 2.5 amperes, average plate current 500 ma dc, plate dissipation 160 watts. Maximum shunt diode ratings: filament voltage 5.4 vac, filament current 15.0 amperes, peak inverse volt 25,000 volts, peak plate current 12.0 amperes, effective rms plate current 800 ma ac, plate dissipation 160 watts. Full details on the EE576A which meets military specifications and other products of Electronic Enterprises Inc. may be obtained by writing to the firm.

(Continued on page 106A)

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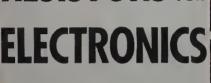
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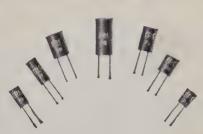
#### **High Megohm Resistors**

Type H Resistors are used in electrometer circuits, radiation equipment and as high resistance standards. Resistance available to 100 million megohms, (10<sup>14</sup> ohms). For utmost stamillion megohms, (10 $^{\rm th}$  ohms). For utmost stability under adverse conditions Type HSD and HSK Hermetically Sealed are recommended. Eight sizes from  $\frac{1}{6}$  inch to 3 inches long are available. Voltage rating to 15,000 volts. Low temperature and voltage coefficients. Standard resistance tolerance 10 $^{\rm th}$ . Tolerance of 5 $^{\rm th}$  and 3 $^{\rm th}$  available. Also matched pairs 2 $^{\rm th}$  tolerance.

RPC is a widely recognized supplier of high quality resistors to industry, Government Agencies and the Armed Forces. Advanced production methods, modern equipment and scientific skill enables RPC to manufacture resistors of highest quality in large quantities at reasonable cost. Modern manufacturing plant is completely air conditioned and equipped with electronic dust precipitators to insure highest production accuracy. RPC resistors are specified for use in instruments, electronic computers, radiation equipment, aircraft equipment and scientific instruments.

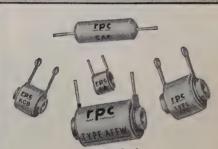
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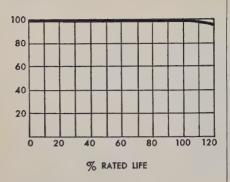


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(Continued from page 104A)

#### Communications Receiver

A new improved model of the Pierson KE-93 Communications Receiver is announced by **Automation Electronics, Inc.**, 1500 W. Verdugo Ave., Burbank, Calif. Designed for either mobile or fixed station operation, it is a 12-tube all-band communications receiver.



Small and compact, the Pierson KE-93 Receiver delivers high over-all perform-

ance on seven bands; 10, 15, 20, 40, 80, 160 meters, and broadcast band.

A new noise-suppression circuitry offers exceptional freedom from all conditions of mobile use. The squelch circuit is sensitive and may be adjusted by its front panel control to open on AM signals too weak to be readable. This permits quiet operation between stations without the danger of passing up weak signals.

The Receiver is of rigid, die-cast construction which makes possible excellent SSB and other types of reception under "in-motion" conditions. The turret drum is housed in a die-cast frame and revolves on ball bearings.

The dual conversion circuitry of this latest amateur receiver is free from image and spurious responses. Quadruple-tuned if networks offer 3 kc selectivity.

Dimensions are 6 wide, 5 high, 9 inches deep. Universal mounting brackets for mobile mounting are included with each receiver.

For additional information and prices, write direct to the manufacturer.

#### Gold Alloy Pot Wire

Secon Metals Corp., 7 Intervale St., White Plains, N. Y., production and development metallurgists, announced the company's new gold alloy, Secon Alloy \$\frac{443}{443}\$, for precision potentiometer wire. Its characteristics are: alternate number: G-80; specific resistance: 80 ohms/circular mil foot; temperature coefficient of resistance (0°-100° C); 0.0006, and tensile strength (PSI×1000): 160.0.

(Continued on page 108A)



## Microwave, Electro-Mechanical and Mechanical Assemblies

#### By ALUMINUM DIP BRAZING

You get top production economy with dip brazing . . . it allows completed assemblies of aluminum parts of all types, sizes and shapes to be joined successfully in one operation. This simplifies complicated precision parts assembly and allows critical tolerances to be maintained.

Whether you are interested in having your own completed assemblies brazed or need complete manufacturing and production facilities from your plans . . . depend on John Gombos Co., Inc., to meet your most exacting and difficult requirements. All products guaranteed to meet most rigid specifications. Ask for our complete facility list.

COMPLETE ALUMINUM DIP BRAZING FACILITIES

Model Shop • Tool Room • Turret Lathe Dept. • Screw Machine
Dept. • Engine Lathe Dept. • Milling Dept. • Inspection Dept. •
Electrical Test Assembly Dept. • and Additional Facilities

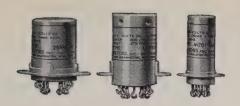


arts can be brazed in one operation and held operation tolerances.



SCROLL HOUSING. 1/32 TK 61 ST Production time reduced from other methods 6 hrs. o 1 hr. with no distortion or sizing





HEW ANOTHER PLICORS EXCLUSIVE EITHER DRY 2PDT. APDT EPPTY ANOTHER PLICORS EXCLUSIVE RELAY FOR EITHER DRY 2PDT. APDT EPPTY ANOTHER PLICORS AND FOR EITHER DRY 2PDT. APDT. LAND TO MIL-R-25018 (USAF) AND INTERSOF HERMETICALLY SEALED SUB-MINIATURE RELAYS

ELANDING MANUFACTURERS OF HERMETICALLY

SEALED SUB-MINIATURE

ALL MADE TO MIL-R-25018 (USAF) AND SEALED SUB-MINIATURE

AN PORT WASHINGTON, LONG ISLAND, N.Y. WRITE FOR COMPLETE CATALOG FILTORS, INC. PORT WASHINGTON 7-3850



#### TELEPHONE AND TELEGRAPH EQUIPMENT

Radio Engineering Products is currently producing a number of types of equipment, electrically and mechanically interchangeable with standard Bell System apparatus.

#### CARRIER-TELEPHONE EQUIPMENT

C5 Carrier-Telephone Terminal (J68756). A kit for adding a fourth toll-grade channel to existing C systems is available. • C1 Carrier-Telephone Repeater (J68757) • 121A C Carrier Line Filter • H Carrier Line Filter (X66217C).

#### CARRIER-TELEGRAPH EQUIPMENT

40C1 Carrier-Telegraph Channel Terminal (J70047C) • 140A1 Carrier Supply (J70036A1, etc.) • 40AC1 Carrier-Telegraph Terminal.

#### **VOICE-FREQUENCY EQUIPMENT**

V1 Telephone Repeater (J68368F) • Power Supply (J68638A1) • V1 Amplifiers (J68635E2 and J68635A2) • V3 Amplifier (J68649A) • V-F Ringers (J68602, etc.) • Four Wire Terminating Set (J68625G1) • 1C Volume Limiter (J68736C).

#### D-C TELEGRAPH EQUIPMENT

16B1 Telegraph Repeater (J70037B) • 10E1 Telegraph Repeater (J70021A) • 128B2 Teletypewriter Subscriber Set (J70027A).

#### TEST EQUIPMENT

2A Toll Test Unit (X63699A) • 12B, 13A, 30A (J64030A) and 32A (J64032A) Transmission Measuring Sets • 111A2 Relay Test Panel (J66118E) • 118C2 Telegraph Transmission Measuring Set (J70069K) • 163A2 Test Unit (J70045B) • 163C1 Test Unit (J70045D).

#### COMPONENTS AND ACCESSORIES

255A and 209FG Polar Relays • Repeating and Retard Coils, several types • 184, 185, 230A and 230B Jack Mountings.

## RADIO ENGINEERING PRODUCTS 1080 UNIVERSITY ST., MONTREAL 3, CANADA

TELEPHONE
UNiversity 6-6887

CABLES RADENPRO, MONTREAL



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 106A)

This new gold alloy rounds out the line of precision potentiometer wire from 37 to 610 ohms/circular mil foot, (including the popular 180-ohm and 400-ohm platinum alloys), all in various precious metals and low temperature coefficient of resistance.

For further data, write directly to Secon.

#### Pulse Transformer

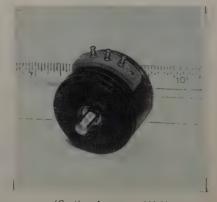


A number of new specially designed STAT-TRAN\* pulse transformers have been developed by Pulse Engineering, 2657 Spring St., Redwood City, Calif., for use in transistor blocking oscillating circuits. Using a flat-bed ferrite core with very high permeability,  $(2400 \mu)$  these new units achieve very low leakage inductance and present an excellent impedance match to the transistor. This characteristic plus their extremely low core loss permits the operation of these STAT-TRAN's at repetition rates to 500 kc. In a typical evaluation circuit, a high impedance trigger of 0.4 volt will produce low impedance output pulses essentially equal to the supply voltage. These pulses can be varied from 0.2 to 40 \(\mu\) seconds and are relatively free from effects of trigger amplitude, rise time and width. Dimensions of these miniature pulse transformers are  $\frac{7}{16}/D \times \frac{3}{4}$  inch L.

#### \* Reg. T.M.

#### Precision Potentiometer

Resistance values from ½ ohm to 500,000 ohms with standard linearity of 0.5 per cent are available in the new Model WP1-5/8 precision potentiometer manufactured by Waters Manufacturing, Inc., Boston Post Rd., Wayland, Mass.



(Continued on page 110A)

## the first really new paper tubular capacitor... **AEROVOX "WHITECAP"** "WAX-FREE

### TYPE V84 TUBULAR CAPACITOR!

Aerovox announces the development of a WAX-FREE paper tubular capacitor with electrical characteristics surpassing all others . . . even the best molded units.

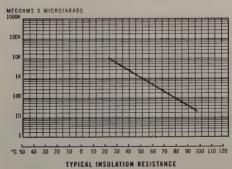
Aerovox "WHITECAP" capacitors offer a distinctive white case, completely free of wax. The absence of any wax facilitates handling and assembly procedures. No dripping and no gummed-up machines. Light in weight and clearly marked, these units will enhance the appearance of any assembly.

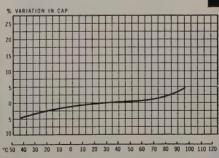
Aerovox "WHITECAP" capacitors are superior electrically over ALL other conventional paper tubulars including molded units. Outstanding humidity resistance ... far greater than ever known before in units designed for radio-TV applications. Highest Insulation Resistance ever offered before in a paper tubular. Wide temperature range . . . low-power-factor. New standards of reliability backed by millions of hours of life and service tests.

Operating Temperatures  $-40^{\circ}$ C to 85°C at full voltage rating and to 100°C with voltage rating of 75%

**Power-Factor** — at room temperature will not exceed 1%

Humidity — will withstand 95% relative humidity at 40°C in accordance with RETMA Specification RS164 except that exposure will be increased to 500 hours instead of 100.





Immediate delivery on all production quantities. For full details contact your local Aeroyox Sales Representative or write immediately to...

## OVOX CORPORAT

MASSACHUSETTS October, 1957

## TELREX LABORATORIES

Designers and Manufacturers of

#### COMMERCIAL SERVICE "BEAMED-POWER" ARRAYS

Calibrated for the commercial 13 to 14 mc. band. Other frequencies available.

Model Illustrated No. CX-13-14

Precision Tuned, Matched and Calibrated for easy assembly and repetition of our Specifications at your site, providing optimum gain per element and hi-signal-to-noise, hi-signal-to-interference "Balanced Pattern."

Electrical Specifications: Gain 8 db, F/B ratio 28 db, V/S/W/R 1.2/1 or better! Impedance, 52 ohm thru coaxial halfwave "Balun" (supplied). Power capacity 5 KW — Higher power models available at extra cost.

Mechanical Specifications: Wt. 60 lbs., 3" OD x 26 ft. boom, taper swaged elements, tapering from 13%" OD to ½" OD, incorporating stainless steel hardware, "Borg-Warner" Cycolac moldings, ¼-20 S.S. junction terminals and heavily camium plated mounting plate. Wind surface area: 7 sq. ft. Wind load at 100 mph; 210 lbs.

Price \$338.00 f.o.b. Asbury Park, New Jersey Available three (3) days after receipt of order. Descriptive literature on request.

Telrex is equipped to design and supply to our specifications or yours, Broadband or single. frequency, fixed or rotary arrays for communications, FM, TV, scatterpropagation, etc.

Consultants and suppliers to communication firms, universities, propagation laboratories and the Armed Forces.

COMMUNICATION & TV ANTENNAS SINCE 1921

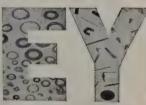
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METAL









#### **ENGINEERED CONTACTS, SLIP RINGS & ALLOYS**

Ney designs and makes to customers' specifications sliding contacts, slip rings and assemblies, commutator segments and assemblies, brush and brush holder assemblies, and precious metal resistance wire. Consult Ney's Engineering Dept. and find out how precious metals can improve your products.

THE J. M. NEY COMPANY, P.O. BOX 990, DEPT. I, HARTFORD 1, CONN.

Specialists in Precious Metal Metallurgy since 1812



Ney has just built this modern new plant to give you even better products and better service.

PARTS PI

SMALL PARTS PLAY A BIG PART IN PRECISION INSTRUMENTS . NEY'S SMALL PARTS



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 108A)

The Model WP1-5/8 linear or nonlinear precision potentiometer is contained in an anodized aluminum case 15 inches in diameter and  $1\frac{1}{32}$  inches deep behind the panel. Turret-type terminals mounted on a fungus-proof insulating strip of highimpact Epon-Glass Laminate are provided for circuit connection. Servo or 3-hole mounting are standard; bushing mount is also available, in a case  $\frac{25}{32}$  inches deep. Shaft diameter for both models in ½ inch. Standard resistances are 50, 100, 200, 500, 1000, 2000, 5000, 10,000, 20,000, 25,000, 40,000, 50,000 and 100,000 ohms; ranges beyond these are furnished on special order.

A data sheet describing the Waters WP1-5/8 linear and nonlinear precision potentiometer is available from the firm.

#### Toroidal Transformer

Advance Industries, Inc., 640 Memorial Dr., Cambridge, Mass., has designed and developed an entirely new laminar toroidal transformer which is said to offer greater performance, yet cost less than conventional stack transformers.



Particularly applicable in transistorized circuits used in radio, television and other commercial applications, the new product is based on a simplified, efficient design. It realizes up to 40 per cent saving in over-all materials compared to stack transformers and results in flat response over wider frequency ranges.

This new concept in transformer design also effects several other "by-product" benefits, such as better form factor, reducing size as well as weight considerably, and increased uniformity of electrical charac-

Advance Industries is currently producing a line of these units from subminiature sizes to moderate sizes, in power ratings up to 30 watts for commercial

In the near future, hermetically sealed versions for military applications will be available.

(Continued on page 112A)

PARTS



Microwave cooking shaves hours from food preparation time. This is a home-type electronic oven developed by Raytheon for production by appliance manufacturers,

## Meals in minutes by electronicsin permanent magnet equipped range

Microwave energy does the cooking in this domestic electronic oven based on Raytheon's "Radarange" for the restaurant industry. Microwaves are

> far higher in frequency than broadcast waves-fact, the magnetron tube (at left) steps up the vibrations to an incredible 2,450,000,000 times a second!

A vital part of the magnetron is

Permanent magnet is C-shaped casting at right of magnetron; box on top is filter assembly.

CRUCIBLE

the Crucible Alnico permanent magnet shown in the inset.

This is one of many practical applications for Crucible Alnico permanent magnets. Crucible has been a leading producer of permanent magnets, known for their consistently higher energy product, ever since Alnico alloys were developed. You can now order them sand cast, shell molded, or investment cast to every size, shape, or tolerance needed.

It's why an increasing number of manufacturers find the answer to their magnet problem at Crucible. Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh 22, Pa.

first name in special purpose steels

Steel Company of America



Freeze them . . . boil them . . . expose them to extreme mechanical shock . . . HYCOR Type "P" Plastic Encapsulated Toroids maintain their precision performance through it all. Hermetically sealed in an extra-tough plastic compound, they stand up under:

- Temperatures of -55°C. to +125°C.
- 95% humidity . . . boiling salt water
- Amazing degree of mechanical shock
- MIL-C-16923, Type C, specification tests

Easily mounted or stacked on a single screw. High quality turnet terminals can be used to mount other components. Ideal for chassis mounting. Also available cased and unencapsulated.

WRITE FOR BULLETIN STP.





These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 110A)

#### Radiation Monitoring Systems

Riggs Nucleonics Co., 2390 Olive Ave., Altadena, Calif., announces a new completely self-contained battery operated radiation monitoring system, Model GA-3B. Continuous operation for a period of 4 months or better is assured while being virtually maintenance-free except for a battery replacement.



The system consists of a control unit with meter relay, manual reset, 3 or 6 decade log scale, calibration controls, electronic calibration test adjustments and 10 my recorder output.

The Model GA-3BA and Model GA-3A are available with ac-dc power supply (failsafe to dc) and straight ac respectively in fully self-contained units as the GA-3B. General specifications and operation information provides that the Models GA-3B, GA-3BA, GA-3A will measure, display, record and control alarms for gamma radiation from background 0.025 mr/hr to 100 kr/hr or higher in the energy range from 80 kv to 1.3 mev.

#### All-Electronic Chopper

Kearfott Company, Inc., 1378 Main Ave., Little Falls, N. J. announced today the immediate availability of an allelectronic chopper containing no moving parts, which for all practical purposes assures a minimum operating life of 5,000 hours.



(Continued on page 114A)

## Transitron

## Silicon Transistors



ACTUAL SIZE

#### Features ...

- Low I co, typically under .02 μα
- Operation to 175°C
- 200 mw Power Rating
- High Frequency Operation
- High Temperature Tested
- Excellent Stability
- Welded Hermetic Seal

Туре	Minimum Common Emitter Current Gain, B	Maximum Collector Voltage Vce Peak (volts)	Typical Cut-off Frequency (mc)	Maximum Collector Cut-Off Current at 25°C at Ve Max. (ua)
ST42	40	45	11	.5
ST32	40	30	11	5
ST12	40	15	11	.5
ST33	30	30	17	.5
ST13	30	15	17	.5
ST41	20	45	10	.5
ST31	20	30	10	.5
ST11	20	15	10	.5
2N332	9	45	7	50
2N333	18	45	9	50
2N334	18	45	11	50
2N335	37	45	10	50

## . . for high temperature operation

Transitron's NPN silicon transistors are designed for a wide range of small signal applications in the power range up to 200 mw. They will provide dependable operation up to 175°C in circuits such as RF and IF amplifiers, video and audio amplifiers, servo control, switching, and many others.

Manufactured by diffusion in the liquid phase during crystal growth, these transistors are essentially free of parameter drift and instability common in conventional grown junction transistors. Through close process control, these units have exceptionally low I<sub>co</sub> up to their maximum voltage and temperature ratings. As a result, performance reliability can be achieved even at higher voltage levels.

For environmental stability, extensive temperature cycling and storage as well as mechanical and hermetic seal tests are included as a regular part of the manufacturing process.

Send for Bulletin TE-1353

## Transitron

electronic corporation \* wakefield, massachusetts







Regulators

Diodes







MINIATURE

PROBLEM? Send for Bulletin No. TR-81

Actuated by a heater, they operate on A.C., D.C.,
 or Pulsating Current.

- Hermetically sealed. Not affected by altitude, moisture, or other climate changes.
- SPST only normally open or normally closed.

Amperite Thermostatic Delay Relays are compensated for ambient temperature changes from  $-55^{\circ}$  to  $+70^{\circ}$  C. Heaters consume approximately 2 W. and may be operated continuously. The units are most compact, rugged, explosion-proof, long-lived, and — inexpensive!

TYPES: Standard Radio Octal, and 9-Pin Miniature

Also — Amperite Differential Relays: Used for automatic overload, under-voltage or under-current protection.



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 112A)

Although used primarily as a dc voltage into ac voltage converter sensitive to the phase of the reference voltage it can be used to convert ac into a dc voltage.

The primary features of this chopper include the following: zero phase shift, 180° dwell time, wide frequency range 60 cps to 20 kc, unlimited life when properly applied, meets or exceeds the requirements of MIL-E-5272A, Standard 7 pin miniature socket plug-in base. The characteristics of the #333058 chopper (used as modulator) are: reference power 6.3 volts at 2 ma, load current 5 ma maximum, dc signal input 1 mv to 5 volts, chatter none, balance  $-0^\circ$ , ambient temperature range  $-55^\circ$  C. to  $+125^\circ$  C. (No measurable output drift.)

#### Single-Scale Megohmmeter

Keithley Instruments, Inc., 12415 Euclid Ave., Cleveland 6, Ohio, has a new model 510 megohmmeter. It measures six decades of resistance on a single six-inch mirror scale and has 5 to 10 times faster response than conventional ohmmeters, the firm states. Typical uses are: checking of



insulation resistance of motor windings, capacitors, transformers, cables and many appliances; and measurements of surface and volume resistivity in insulating compounds. With its 5, 50 and 500 volt test potentials, the instrument provides a selection of safe voltages for measuring all test samples and for checking voltage coefficients.

Features of the Model 510 include elimination of range-switching, a linear scale with no compression at the high end, negligible drift, simple operating controls, and a guarded, completely shielded input.

Details about the Model 510 are available in Keithley Engineering Notes, Vol. 5 No. 4.

(Continued on page 116A)



of Amperite products.



## 2 NEW **LEAD TYPES**

## Silicon Rectifiers

150ma TYPE (400ma at 25°C)

RATINGS TO 600V. PIV IN BOTH TYPES

#### Features . . .

- Operation to 175°C
- High power handling ability
- Convenient mounting
- Small size
- Hermetically sealed

250ma TYPE (750ma at 25°C)

Two new lead types have now been included in Transitron's expanding family of silicon rectifiers. The subminiature glass units combine high current-voltage ratings with the smallest possible size to provide greater design versatility. For applications requiring ratings in the region of 250 ma per cell, the new standard series is recommended.

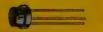
The same high degree of reliability which has been characteristic of Transitron's silicon diodes and stud type rectifiers has been "built into" these new lead types. Extensive environmental testing insures dependability under the most severe operating conditions.

Туре	Peak Recurrent Inverse Operating Voltage (volts)	Maximum Average Forward Current @ 150°C (ma)	Maximum Average Forward Current @ 25°C (ma)	Maximum Inverse Current @ 150°C Full Load (ma)
		INIATURE TY	PES	
TG62	600	150	400	.2
TG42	400	150	400	.2
TG22	200	150	400	.2
	STA	NDARD TYPI	ES	
1N547	600	250	750	.3
1N540	400	250	750	.3
1N538	200	250	750	.3
1N537	100	250	750	.4

Send for Bulletin TE- 1351

Transitron

electronic corporation • wakefield, massachusetts

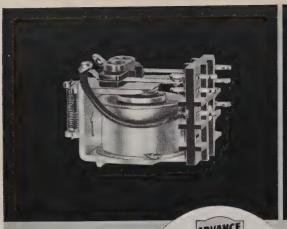














#### ELGIN

announces the



ADVANCE

Low Cost

# lidget Relays

#### ... open or plastic enclosed

Elgin's new GH series combines the high efficiency required of general purpose relays with low cost. Their midget size suits them for installations where space is a problem (see specifications below). Open relays in 5 and 10 ampere ratings and clear plastic dust-tight enclosed 5 ampere relays are immediately available from stock. Specify dependable ELGIN performance... specify GH from your electronic parts distributor!

#### SPECIFICATIONS

NOMINAL POWER REQ.-DC relays, 1 to 2 watts; AC relays, 2 to 3 volt amperes. NOMINAL VOLTAGE-DC relays, 6 to 120 volts; AC relays, 6 to 220 volts. (On specification, DC voltage coil up to 220 volts or AC voltage coil up to 440 volts can be supplied.)

RESISTANCE - DC relays, 25 to 8,000 ohms; AC relays, 4 to 5,000 ohms.

PULL-IN CURRENT VALUES-7.2 Milliamps max, at 2,500 ohms; 5.0 milliamps max, at 5,000 ohms.

DUTY CYCLE-continuous.

TEMPERATURE RANGE-  $-55^{\circ}$  to -85°C when specified.

INSULATION RESISTANCE - 100 meg-

DIELECTRIC STRENGTH - standard: 500 volts RMS. (When specified, 1,000 volts RMS can be met.)

MAXIMUM WEIGHT-2 ounces.

#### GHA SERIES, 5 amp. open relay

Contact rating, 5 amps. resistive, 2 amps. inductive at 115 volts AC or 26.5 volts DC. Contact material is fine silver, 1C,2C,3C arrangements only, Relay is 1.1" high, 1.732" long and .937" wide. Contact terminals can be used as solder lugs or for printed circuitry.

(Also available: GHB series, 10 amp, open relay.)

GHP SERIES, 5 amp. clear plastic enclosed relay.

Dust-tight plug-in. Contact rating, 5 amps. resistive, 2 amps. inductive at 115 volts AC or 26.5 volts DC. Contact material is fine silver, available in 1C or 2C arrangements only. Enclosure is  $2^{11}/_{16}$ " x  $1^{13}/_{32}$ " overall.  $2^{1}/_{8}$ " overall length above chassis.



116A

#### **ELECTRONICS DIVISION**

ELGIN NATIONAL WATCH COMPANY

2435 N. Naomi Street, Burbank, California



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 114A)

#### Low Cost Computer

A low cost analog computer has been announced by Donner Scientific Co., Concord, Calif. Priced at \$15,035.00 this computer is capable of solving problems to the same accuracy as computers costing thirty or forty thousand dollars, the firm claims.



Among the features especially worth noting in the standardized, mass-produced Donner Model 3100 is the amplifier overload system. During the initial run of new problems, setup and scaling must be checked. Should a momentary overload occur, an indication of which amplifiers have overloaded would help catch sealing errors quickly.

Each Model 3101 amplifier unit contains 10 stabilized amplifiers in dual modules.

Among the other features and characteristics of the new Donner 3100 are the use of silicon diodes in the power supply and the reference supply, resulting in better regulation and 20 per cent weight reduction. The reference supply provides a positive voltage equal to the negative within 1 millivolt (nominal  $\pm 100$  volts  $\pm 1$ millivolt).

Owing to its conservative design throughout, none of the tubes in the computer need be selected. Use of modular plug-in amplifiers speeds maintenance. These are particularly important considerations when the computer is used outside well-staffed and equipped installations.

Starting with as few as 10 amplifiers and 20 potentiometers, the user can build up a console of 30 amplifiers and 40 potentiometers as his needs dictate. Computer consoles may be "slaved" to each other for further expansion.

#### Jobber Catalog

Newark Electric Co., 223 Madison St., Chicago, Ill. and 4736 W. Century Blvd., Englewood, Calif., issued their new, biggerthan-ever 1958 Catalog No. 68. This Free Book, complete in every way, contains 360 pages of the latest, up-to-the-minute de-

(Continued on page 118A)



#### MODEL 372 SLIDING COAXIAL TERMINATIONS

This equipment, available only from Narda, provides the most convenient means for evaluating the residual VSWR of coaxial slotted lines. VSWR of the element is 1.05 or less; covers range from 2000 to 12,400 mc.

N Connector, male or female \$110 C Connector, male or female \$116



#### **MODEL 371 FIXED COAXIAL TERMINATION**

This Narda coaxial termination is the first and only to cover the entire frequency range from S to X band. Same range and element VSWR as above.

N Connector, male or female \$55

C Connector, male or female \$58



#### HIGH DIRECTIVITY COUPLERS

The 40 db High Power Coupler is another exclusive Narda product. Similar to standard types, except that coupling irises are in the narrow wall, it may be used at full rated power of the waveguide size. Nominal coupling value is 40 db; directivity 40 db. Directivity for 3, 6, 10 and 20 db couplers is also 40 db. Standard cover flanges on primary line; low VSWR termination and standard cover flange on secondary. All bands covering frequencies from 2600 to 18,000 mc.



#### STANDARD REFLECTIONS

Narda offers five values of reflections for each of six different waveguide sizes. ... the most complete choice we know of! Provides calibrated reflections or VSWR's for use in standardizing reflectometers or calibrating slotted line impedance meters.

#### SPECIFICATIONS

Reflection Coefficient	0.00	0.05	0.10	0.15	0.20
Accuracy	0.002	0.0025	0.0035	0.0045	0.007
VSWR Equivalent	1.00	1.105	1.222	1.353	1.50

Models for 2.60 to 18.0 kmc, from \$125 to \$300

#### Microwave engineers-

# Where can you use these exclusive features offered by narda?



#### **Waveguide and Coaxial IMPEDANCE METERS**

Exclusively in Narda Waveguide and Coaxial Impedance Meters, the carriage mounting and drive mechanism are integral with the precisely machined transmission line casting. This insures permanent accuracy and freedom from slope errors—no more tedious adjustment or possibility of misalignment.

Other features include angle-mounted scale and vernier for optimum visibility; readily removable supporting pedestal; and smooth carriage travel action. Waveguide models, accurate for VSWR's of 1.01, are available for complete coverage from 2600 to 18,000 mc; N or C Connector coaxial models, from 1500 to 12,400 mc.

#### **WAVEGUIDE IMPEDANCE METERS**

Frequency (kmc)	Narda Model	Residual VSWR	Price
2.6 — 3.95	224		\$425
3.95— 5.85	223		350
5.3 — 8.2	222	1.01	325
7.0510.0	221		270
8.2 —12.4	220		250
12.4 —18.0	219		270

#### COAXIAL IMPEDANCE METERS

Frequency (kmc)	Connectors (One Male, One Female)	Narda Model	Price
1.5 to 12.4	Series N	231	\$360
1.5 to 12.4	Series C	232	390

#### Complete Coaxial and Waveguide Instrumentation for Microwaves and UHF-including:

DIRECTIONAL COUPLERS

TERMINATIONS

FREQUENCY METERS

HORNS

TUNERS

ECHO BOXES

SLOTTED LINES

BENDS

ATTENUATORS

STANDARD REFLECTIONS

**BOLOMETERS** 

THERMISTORS

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The Narda Microwave Corporation 160 Herricks Road Mineola, N. Y. Dept. PI-I



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#### for industrial applications PROMPT SHIPMENTS

For any part of your operation that depends on electromechanical switching, these "telephone-quality" relays by Stromberg-Carlson will provide unsurpassed reliability.

Proven by many years of meeting the exacting demands of the telephone industry, Stromberg-Carlson twin-contact relays are now available for industrial application.

These "telephone-quality" relays are available in many types, of which the following are representative:

Type A: a general-purpose relay especially adapted to the control of switching operations. Approximate size:  $2^{21}\%2''$  high, 7%'' wide with 20 Form "A" springs (maximum).

Type B: a gang-type relay— $2^{21}$ %2" high, 2%" wide—which can be equipped with 60 Form "A" spring combinations (maximum). The Type BB relay accommodates up to 100 Form "A" spring combinations. Size:  $2^{25}$ %2" high, 4%1" wide.

Type C: two relays on the same frame; mounts in the same space as the A type. It is especially effective where space is at a premium.

Type E: interchangeable with many other makes. It combines the time-proven characteristics of the A relay with a new universal mounting arrangement common to many other brands.

Complete specifications of all Stromberg-Carlson relays are contained in Bulletin T-5000R, available on request.



#### STROMBERG-CARLSON

A DIVISION OF GENERAL DYNAMICS CORPORATION TELECOMMUNICATION INDUSTRIAL SALES 115 CARLSON ROAD • ROCHESTER 3, N. Y.



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 116A)

velopments in Industrial Electronics, High Fidelity, Radio, Television, and Amateur Equipment. Newark's new quantity price breakdown set up will be especially valuable to all.

Newark's new Catalog No. 68 has set the pace with the most item-crammed book yet...capacitors, test equipment, tubes, hardware, tools, resistors, transformers are among the items mentioned.

#### **Telemetering Oscillator**

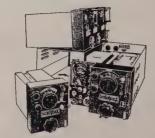
United Electrodynamics, 1200 South Marengo, Pasadena, Calif. announces a completely transistorized voltage controlled subcarrier oscillator for FM/FM telemetering system application which provides extreme environmental capabilities with a minimum of space and weight. This oscillator will operate with specified performance under vibrations of 50 G up to 500 cps and 20 G up to 2000 cps. It will similarly withstand shocks and accelerations of 200 G or greater. It is unaffected by altitude.

The unit includes a precision, temperature stabilized bandpass filter which produces an output signal with a minimum of

(Continued on page 120A)

#### **AN/APT-5 TRANSMITTERS**

Make excellent power signal generators for the range 300-1625MC., rated at 58 watts CW RF at 500MC. Contains blower-cooled 3C22 in re-entrant cavity with precision cathode, plate and loading controls, plus 6 tube AM modulator and amplifier flat from 50KC to 3MC. (easily converted to audio) with phototube noise generator. 115 volt 60 cycle flament supply. New, in export packing, with matching special plugs, lecher line, alternate feedback assembly, manual, audio conversion instructions and technical data, at \$250.00. Limited stock,



#### AN/APR-4 RECEIVERS

with all five Tuning Units covering 38 to 4,000MC, ; versatile, accurate and compact, the aristocrat of lab receivers in this range. Complete with wideband discone antenna, wavetraps, 100 page manual, plugs, cables and mobile accessories as required.

The AN/APR-4 has been our specialty for over ten years, Over 40 hours of laboratory time is invested in each complete set immediately prior to shipment, so that we can not only guarantee it to pass A-N specifications, but to have the inevitable mass-production irregularities corrected and the latest improvements added. We maintain a complete stock of spare parts and expect to service our customers' sets indefinitely. Write for data sheet and quotation.

#### TEST EQUIPMENT

of highest quality, new and reconditioned, military surplus and top commercial brands in stock at money-saving prices. Let us quote to your requirements.

ENGINEERING ASSOCIATES
434 PATTERSON ROAD, DAYTON 9, OHIO

## ULTRA-LOW DISTORTION AMPLIFIER 0.005% Distortion At 50 Watts



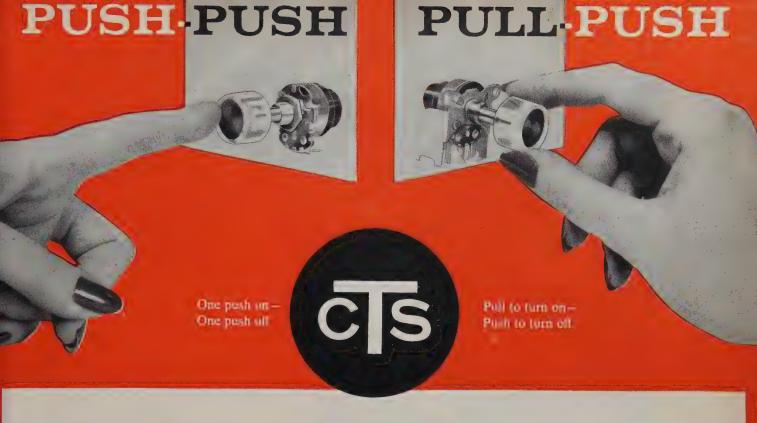
Model UF-101

Krohn-Hite ULTRA-LOW DISTORTION 50 WATT POWER AMPLIFIER incorporates 80 db of negative feedback with harmonic and intermodulation distortion of less than 0.005%. The response is flat ±0.5 db from 0.5 cps to 30 kc. Excellent transient response is maintained at all output impedances from 2 to 450 ohms by switching the feedback to the output transformer secondary winding being used. A dynamic range of 110 db is obtained by careful shielding and the use of d-c on the heaters of the first two stages. Four type 6550 output tubes are operated in class AB<sub>1</sub> to deliver 50 watts conservatively. This amplifier provides a lower distortion laboratory signal source and is useful in the development and testing of high quality audio equipment. Price \$425.00 f.o.b. factory.

For Further Details Write Dept. IRE

#### **Krohn-Hite Corporation**

580 Massachusetts Avenue • Cambridge 39, Massachusetts



## Two new switchcontrols

Volume setting unaltered by **ON-OFF** operation

Just switch on and walk away. No coming back or waiting for further adjustment after warm-up.

Volume can be changed instantly as desired by rotating shaft . . . or can remain indefinitely at any selected setting regardless of on-off switch operations.

Push-push switch available with either 3 amp 125V rating (Type J) or 6 amp 125V rating (Type TJ). Pull-push switch available with 3 amp 125V rating (Type K). Both switches available in many special terminal and control combinations.

Write today for Data Sheets containing dimensional drawings and complete technical details.

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The most complete line of variable resistors and associated switches available is manufactured by CTS. Consult CTS Specialists on all your control problems.



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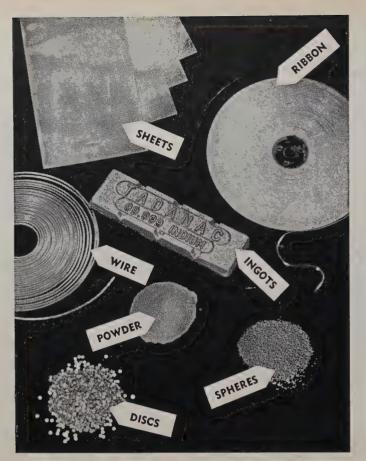
Many types of variable resistors now in production at our South Pasadena plant. Your coil, transformer and compression molding business also invited. Prompt delivery. Modern versatile equipment. L. A. phone CLinton 5-7186.

Burton Brown & Additional

CHICAGO TELEPHONE SUPPLY Corporation

ELAHART : INCIANA

The Exclusive Specialists in Prevision Mass Production of Variable Resistors



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Indium or indium alloys in ingots, sheets, wire, powder, ribbon, and pellets (disc or spherical) are supplied by us to leading U.S. manufacturers of electronic equipment. These and other forms prepared to your own requirements are available in two grades:

Tadanac High Purity - approximately 99.999% In Tadanac Standard Grade - guaranteed 99.97% In As one of the world's leading primary producers of indium, we apply the services of our Research and Development Division to assist our customers in obtaining the full benefits of this most versatile metal.

Other high purity TADANAC BRAND METALS

Zinc - 99.9995% Lead - 99.9998%

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Our prices include customs' duties, and we handle all customs procedures.

For further information or quotations contact:



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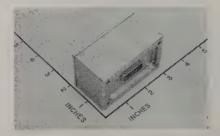
215 St. James Street West, Montreal, Canada

5761-ME



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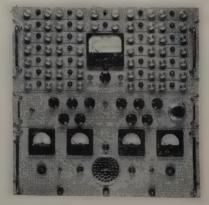


distortion as well as preventing intermodulation between channels. An input impedance of 500,000 ohms assures successful operation with high impedance sources. Linearity and stability are maintained over an operating temperature range up to  $+180^{\circ}$  F.

The unit is packaged in a modular form employing a single connector. Dimensions are approximately  $2.0 \times 1.9 \times 3.0$  inches with an approximate weight of 12 ounces. Units operating at all standard frequencies and deviations with standard input signal levels are available.

#### Telemetering Decommutator

Designed for use in airborne or trailer-installed telemeter receiving stations and in portable ground checkout equipment, this new 27-channel decommutation system occupies  $19\frac{1}{2}$  inches of panel height in a standard relay rack. Overall depth is 13 inches. The new Model TDS30-1 Decommutation System designed by the Arnoux Corp., 11924 W. Washington Blvd., Los Angeles 66, Calif. is completely self-contained within three chassis assemblies consisting of: Gating Unit (Top), Pulse Selector (Middle) and Regulated Power Supply (Bottom). Novel circuitry design

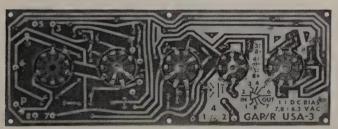


does not reflect errors due to center frequency drift of subcarrier oscillators, drift of discriminator dc output level, or tape playback speed errors. Built-in test selector permits visual inspection of waveforms throughout system for quick malfunction detection. Neon indicators on each gating unit give continuous visual indication of

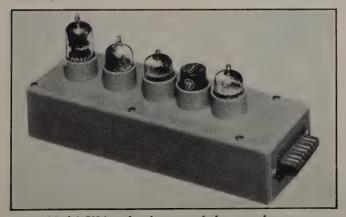
(Continued on page 124A)



## PHILBRICK PRINTED CIRCUIT AMPLIFIER



Underside of Model USA-3 showing printed circuit, amplifier connection scheme, and connecting terminals.



Model USA-3 showing one of the several types of modular packaging available at extra cost.

#### Model USA-3

High performance combined with the reliability and compactness of a printed circuit design are featured in the new Philbrick Universal Stabilized Amplifier, Model USA-3. It is ideally suited for applications to instrumentation, control and analog computation. Extremely high open-loop d-c gain, wide bandwidth, low noise and wide output range are important performance characteristics of this new chopper stabilized amplifier. An interesting design feature makes this instrument safe against self-destruction, even under prolonged overload conditions or direct grounding of its output. At a price of only \$95.00, it offers more performance per dollar than any other amplifier on the market today. Write to George A. Philbrick Researches, Inc., Dept. 11, for Bulletin USA-3.

## PHILBRICK RESEARCHES, INC.

230 Congress Street, Boston 10, Massachusetts





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(Continued from page 120A)

correct sequential operation. System accepts all standard RDB inputs, either PAM or PDM, at any repetition rate from  $2\frac{1}{2}$  to 40 RPS. Either single ended or push pull input signals are accepted. Outputs may be operated single or double ended. Over-all linearity is within  $\pm\frac{1}{2}$  per cent at maximum signal level. Long term level drift is within  $\pm\frac{1}{2}$  per cent, and gain drift is negligible. Power required is 115 volts, 60 cps, single phase. Optional 115 volts, 400 cps power supply available for airborne applications.

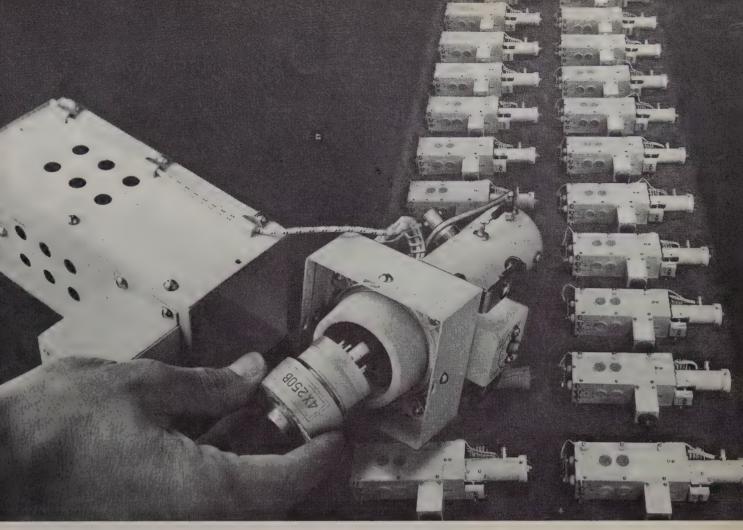
#### Carrier-Telephone Terminal

Radio Engineering Products, Ltd., 1080 University St., Montreal 3, Canada, has developed the type F1450 carrier telephone terminal for four-wire cable or radio circuits. It is a miniaturized one-plus-four channel voice-multiplex system of advanced design. The new designs are said to be less than one-tenth the cubic content of equipment currently in use, and less than one-quarter the weight. They use less than one-fifth as many tubes, of only one instead of 8 to 10 types, and require one-seventh as much power.



This terminal provides four toll-grade carrier-derived telephone circuits, one voice-frequency order-wire circuit which may be of toll grade, and frequency space for up to 20 carrier-telegraph circuits, on 4-wire cable, open-wire, or radio circuits, in a transmission band of from 300 to 20,000 cps. It includes ringing converters, operating at 3450 cycles either in-band or out-band, on either 20-cycle or dc loop signals, complete test and line-up facilities automatic transmission regulator, and attendant's telephone set. It operates from 115 or 230 volts 45 to 66 cps, requiring only 43 watts. The complete terminal, shock-mounted, in its carrying case, measures  $15\frac{3}{16}$  inches long by  $9\frac{7}{8}$  inches high by  $9\frac{11}{16}$ inches deep, (0.84 cubic foot) and weighs 67 pounds. Operation over standard loaded spiral-4 field cable is possible at distances up to 40 miles without intermediate repeaters. Only ten electron tubes are required, and these are of a single type.

(Continued on page 126A)



Final Amplifier Sections of Kaar Type TV-3 CAA Transmitters

## EIMAC 4X250B Replaces 4X150A in CAA Ground Station VHF Transmitter

Kaar Engineering uses the Eimac 4X250B in the final amplifier of its TV-3 CAA transmitter, for several outstanding reasons:

- 1. The Eimac developed 4X250B meets the CAA efficiency requirements.
- 2. In the TV-3 as in most other equipment, the 4X250B is unilaterally interchangeable with the 4X150A.
- **3.** Kaar finds that uniform tubes are assured by Eimac's exclusive long-pulse cathode evaluation testing.

**4.** Eimac ceramic construction makes this tube highly immune to damage by heat or shock.

In addition, ceramic permits optimum processing techniques that lead to tube reliability and longevity.

As one engineer put it, "We plugged in an Eimac 4X250B and immediately saw the difference."

For further information on Eimac tubes that can take it, consult our Application Engineering Department.

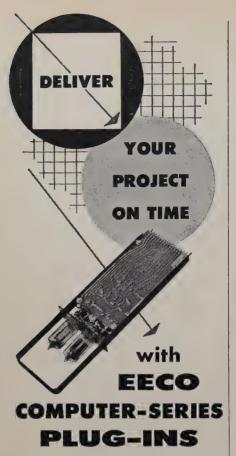
## EITEL-MCCULLOUGH, INC.

Eimac First with Ceramic Tubes that can take it



#### EIMAC CERAMIC 4X250B OPERATES AT FULL RATINGS THROUGH 500MC MAXIMUM RATINGS

			FM	. AM .	SSB			.FM	AM	SSB
D-C Plate Voltage			2000	1500	2000	Screen Dissipation, watts		12	8	12
D-C Screen Voltage .		,	300	300	400	Grid Dissipation, watts .		2	2	2
D-C Grid Voltage						Plate Dissipation, watts .		250	165	250
D-C Plate Current, ma .			250	200	250	•				



Originally developed for EECO custom systems and proven in critical use, new EECO Computer-Series Plug-ins represent a refinement of the building-block concept to a degree hitherto unknown. Each of the full line of reliable, tested, and proven circuits is a complete off-the-shelf packaged function, performance-engineered for application where ultra-conservative design at the component level is essential because of system complexity.

New EECO Computer-Series Plug-ins enable you to meet your project delivery schedules by reducing systems-development time to a bare minimum and practically eliminating drafting and layout time. Your engineers can concentrate on system design instead of routine circuit detail. Your technicians can cut fabrication time and step up production by performing simple point-to-point wiring instead of wiring complex circuits. And system prototypes can generally be built directly without need for the "breadboard" stage.

Detailed information on Computer-Series Plug-ins, Standard-Series Plug-ins, Systems Development Racks, Power Supplies, D-C Amplifiers ... and other EECO products is available in Catalog No. 856-A. Write for your copy—today.

#### ENGINEERED ELECTRONICS COMPANY

(formerly EECO Production Company)



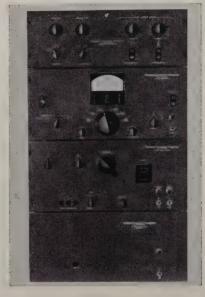
a subsidiary of Electronic Engineering Company of California 506 EAST FIRST STREET SANTA ANA, CALIFORNIA



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(Continued from page 124A)

#### Frequency Analyzer



The Technical Products Co., 6670 Lexington Ave., Los Angeles 38, Calif., announces the availability of the TP-625

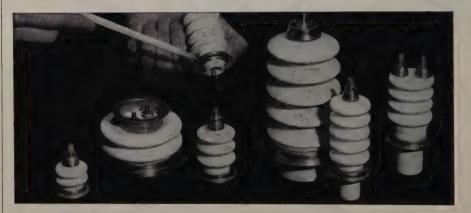
Frequency Analyzer which determines the frequency and amplitude of the individual components of a complex wave within the frequency range of 2 to 25,000 cps. When equipped with its auxiliary equipment, the TP-629 Control Panel and the TP-628 Servo Drive, the TP-625 Frequency Analyzer will automatically track to a frequency established by the speed of the equipment under analysis. Odd, even or fractional ratios can be established by the control panel. The auxiliary equipment requires only one external signal, a function of the fundamental frequency of the equipment being analyzed.

#### Pull-Push Switch



A new pull-push switch which switches radio, TV and other electronic equipment on and off without altering volume setting is now offered by **Chicago Telephone Supply Corporation**, Elkhart, Indiana. Re-

(Continued on page 128A)



For exacting, high-temperature applications...

## **CERAMASEAL LEAK-TIGHT TERMINALS**

Assuring you savings in installation and operation, these Ceramaseal high-temperature terminals are 100% leak-tested and guaranteed leak-tight when shipped.

High-alumina ceramic and metal parts of Ceramaseal terminals are joined by an exclusive process to form a high-strength, long-life molecular seal.

Brazing, welding or soldering techniques can be used for installation, without resulting damage to the seal, thus eliminating costly rework or replacement. For brochure and spec sheets, or complete information on special high-temperature terminals, write: Ceramaseal, Inc., Box 25, New Lebanon Center, New York.

Supplying High-temperature, Quality Terminals for Five Years

## CERAMASEAL, Inc.

## **Production and Laboratory TEST TIME...**



# REDUCED from hours TO MINUTES!

# Federal 200K SWEPT FREQUENCY GENERATOR

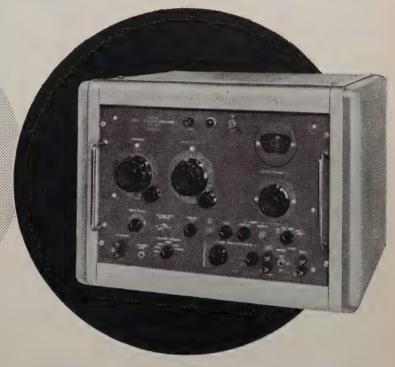
For the first time . . . swept frequency convenience with point-by-point accuracy!



## Features of a Federal COMPATIBLE SYSTEM:

- Measures complete frequency response to 1% accuracy...uniform performance 20 cps to 200 KC.
- Continuous presentation of circuit adjustment effects observed instantaneously.
- Marker by-passes unit under test, allowing 1% identification accuracy...no birdies.
- Variety of sweep modes and range of sweep speeds provide maximum compatibility to system under test.
- Permanent photographic records readily available.

For complete data write Dept. S-637



# INSTANTANEOUSLY provides frequency measurements of optimum accuracy—when used in conjunction with a large-screen oscilloscope—

Federal's 200K Swept Frequency Generator—with a Federal large-screen oscilloscope—provides a compatible system of outstanding versatility and efficiency... capable of producing amplitude vs. frequency displays of the highest accuracy. The frequency response plots obtained bring new speed and dependability to production testing and calibration of frequency-sensitive devices. Effects of changes in circuit parameters upon frequency characteristics can be determined instantly, resulting in an optimum design in minimum time.

Federal's 200K produces a constant amplitude ( $\pm 1\%$ ) output voltage of continuously varying frequency from 20 cps to 200 KC, or any increment in this range. Continuous frequency variations are produced by internally generated sawtooth, logarithmic, triangular, or square waveforms at any rate between .1 and 10 sweeps per second. Sweep linearity is  $\pm 2\%$  for full deviation.

A unique, patented feature of the 200K is the  $\pm 1\%$ -accurate frequency marker circuit which positions a marker pulse on the oscilloscope display at any frequency within the instrument's range. This internally generated marker pulse does not go through the unit under test and is unaffected by the deviation rate. Federal 17 and 21-inch oscilloscopes are available for use with the 200K.



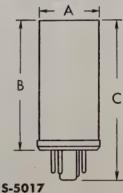
Federal INSTRUMENTS
Industrial Products Division

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION - 100 Kingsland Road, Clifton, N. J.
VISIT IT&T BOOTHS 149-50—NEC SHOW

PROCEEDINGS OF THE IRE October, 1957

# Full Wave SILICON Tube Replacement RECTIFIERS

Where dependability and ruggedness are a "must," Full Wave Silicon Tube Replacement Rectifiers will solve your problems. One of the four standard types described below will meet the requirements of your application.



#### **S-5011** 1N1150

#### Maximum Rating:

Peak Inverse Voltage		
per Section	1600 Volts	Max.
Peak Rectifier Current		
per Section	8000 MA	Max.
DC Output Current		Max.
Ambient Temperature	100°C	Max.

#### Dimensions:

A-1-1/2" O.D. B-2-1/4" C-2-27/32" Four Pin Base

Replacement for Types 80, 82, 83, 83V, 5Z3

#### **S-5017** 1N1237

#### Maximum Rating:

S-5011

S-5017

5-5018

S-5019

Peak Inverse Voltage	
per Section	1600 Volts Max.
Peak Rectifier Current	
per Section	8000 MA Max.
DC Output Current	
Ambient Temperature	100°C Max.
Dimensions:	
A-1-3/16" O.D. B-2-1	9/32" C-3-5/32"

A-1-3/16" O.D. B-2-19/32" C-3-5/32" Octal base

Replacement for Types 0Z4, 5X4, 5Y4, 6AX5, 6X5

#### S-5018

#### 1N1238 Maximum Ratings:

Peak Inverse Voltage	e		
per Section	1600	Volts	Max.
Peak Rectifier Curren	nt		
per Section	800	AM O	Max.
DC Output Current		MA	Max.

#### **Dimensions:**

A-1-3/16" O.D. B-2-19/32" C-3-5/32" Octal base

Ambient Temperature ......100°C Max.

Replacement for Types 5AU4, 5AW4, 5AZ4, 5T4, 5U4, 5V4, 5W4, 5Y3, 5Z4

#### S-5019

#### 1N1239

	.carrings.	
Park Inua	Valtana	

per Section	2800	Volts	Max.
Peak Rectifier Current			
per Section	500	AM O	Max.
DC Output Current	500	AM C	Max.
Ambient Temperature		00°C	Max.

#### **Dimensions:**

A-1-5/16" O.D. B-3-3/4" C-4-5/16" Octal Base

Replacement for Type 5R4

Send for data sheets on any of the above types.



## RECTIFIER DIVISION

DEPT. P5, 415 NORTH COLLEGE AVE., BLOOMINGTON, INDIANA

IN CANADA: 700 WESTON RD., TORONTO 9, TEL. ROGERS 2-7535
EXPORT: AD AURIEMA, INC., NEW YORK CITY



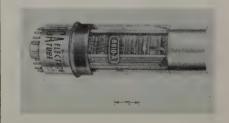
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(Continued from page 126A)

gardless of number of on-off operations, volume remains indefinitely at any selected setting or it may be changed instantly by rotating the volume control. There is no waiting or returning to the set after warm-up to make further adjustment. The switch also makes possible additional styling flexibility in set manufacture. Type K SPST switch has a 3 amp 125 V underwriters' approved rating and is available with either printed circuit or standard solder lug type terminals. The switch can be used with any CTS  $\frac{15}{16}$  inch diameter bushing mounted single section or concentric tandem control.

#### Multiplier Phototube

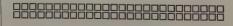
Electron Tube Div., Radio Corporation of America, 415 S. 5 St., Harrison, N. J., announces the 6810-A, an improved and superseding version of the 6810. It features high collection efficiency and reduced electron transit-time spread. This 6810-A has a time-resolution capability in the order of 1 millimicrosecond, high current gain, relative freedom from afterpulses, very small spread in electrontransit time, and very good electron collection from all parts of the useful cathode. These characteristics make it especially well suited for fast coincidence scintillation counting.



Design features of the 6810-A include a semitransparent cathode on the curved inner surface of the face end of the bulb; a minimum cathode diameter of 1½ inch; a faceplate with a flat external surface to facilitate the mounting of flat phosphor crystals in direct contact with the surface; and 14 electrostatically focused multiplying (dynode) stages.

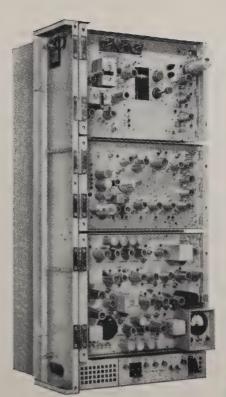
The spectral response of the 6810-A covers the range from about 3000 to 6500 angstroms. Maximum response occurs in the blue region at approximately 4400 angstroms,

(Continued on page 142A)



## Use your IRE DIRECTORY It's valuable

## UNIQUE



Full utilization of the superior characteristics of tropo scatter communication is achieved by REL *combining* diversity receiver equipment. These notable advantages are unique with REL diversity receivers:

1) Positive improvement in signal-to-noise ratios over single receiver operation, when received signals in each receiver are approximately equal in quality:

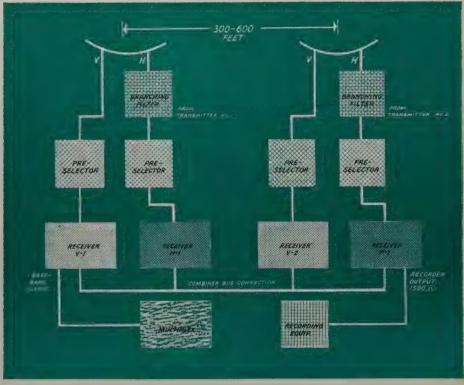
3 db for dual diversity

4.75 db for triple diversity

6 db for quadruple diversity

- Signal-to-noise ratios at least equal to that of best receiver in the diversity combination.
- 3) Circuit reliability enhanced by combining all signal paths.
- 4) Response time of the combining action optimized for both voice and teletype reception to an attack time of 0.2 milliseconds.
- 5) Combiner dynamic response increased to 40 db.
- 6) The adaptability and versatility of all receivers further augmented by a 1500 ohm output for standard graphic recording equipment.

The same imagination and skills which devised this apparatus are available for solving your specialized radio problems.





## Radio Engineering Laboratories • Inc.

29-01 Borden Ave - Long Island City ., N. Y.

STillwell 6-2100 • Teletype: NY 4-2816

Canadian Representative:

Ahearn & Soper Co • 384 Bank St • Ottawa

Typical quadruple diversity operation of REL combining receiver. Output to multiplex available from all receivers. V = vertical polarization, H = horizontal.





The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

Proceedings of the IRE
I East 79th St., New York 21, N.Y.

#### RADIO ENGINEER

As technical consultant to large national trade association in two-way mobile and microwave radio fields. Also acts as contact man with FCC and other associations on technical matters and frequency allocations. Location; Washington, D.C. Send complete details in first application. Reply Box 1053.

#### ELECTRONIC ENGINEERS AND PHYSICISTS

The U. S. Department of State has several career openings for Electronic Engineers and Physicists in Washington and overseas. For further details, write or contact the Office of Security, Department of State, 515 22nd St., N.W., Washington 25, D.C.

#### **ENGINEERS**

Scholarships to the value of \$1500.-\$2100, per annum are offered for advanced study and research leading to the degrees of M.Sc. and D.Sc.

Additional payments up to \$24.00 per week may be made for part-time teaching assistance. Applications and inquiries to The Director, Dept. of Electrical Engineering, Laval University, Quebec, P.Q.

#### ELECTRONIC CIRCUIT DESIGN ENGINEERS

Several years experience and graduate training desirable (but not required) for challenging circuit design problems. Ability to work in small, outstanding group on varied high caliber design projects i.e. computer techniques application, data accumulation and reduction, pulse amplifier and discriminator design. Phillips Petroleum Co. Atomic Energy Div., P. O. Box 1259-BG, Idaho Falls, Idaho.

#### **PHYSICIST**

Applied Physicist (MS or EE MS.) to initiate new basic studies and electrical analysis of snap-acting switches. These will involve general investigations of steady state and transient conditions as well as special problems such as the effect of external magnetic fields on arc movement. Temperature humidity and pressure of surrounding gas must be considered. This will require a strong theoretical background and the ability to experiment and evaluate. Send resume to Mr. M. H. Nelson, MICRO SWITCH, Div. of Minneapolis-Honeywell Reg. Co., Freeport, Illinois.

#### DESIGN ENGINEER

Design Engineer with specialized experience in servo-mechanisms, circuit and analog computer design utilizing vacuum tubes, transistors, and magnetic amplifiers. Apply Supervisor of Engineering Placement, AiResearch Manufacturing Co., 9851 Sepulveda Blvd., Los Angeles 45, Calif.

(Continued on page 133A)

#### ELECTRONIC ENGINEERS

#### MECHANICAL ENGINEERS

#### JUNIOR TO SENIOR LEVELS

NEW OPPORTUNITIES IN DESIGN & DEVELOPMENT

- RADAR
- PULSE WORK
- MICROWAVE
- CIRCUIT DESIGN

#### For Communications Equipment

RADIO RECEPTOR CO., Brooklyn, N.Y. and AUTO-MATIC MFG. CO., Newark, N.J., both in the fore-front of semi-conductors & communication equipment development, have recently combined their backgrounds, scientific know-how and resources in a vast new program.

For smart, competent engineers seeking an opportunity to enter such a program at the right time, the best time, TOP PAYING TIME in terms of both CASH and CAREER . . .

THE TIME IS NOW!

Send Resume To: Mr. S. Winston

#### RADIO RECEPTOR CO.

A Division of General Instrument Corp. 240 WYTHE AVE., BKLYN, N. Y., EVergreen 8-6000

Zone\_\_\_State\_



(Continued from page 130A)

#### SENIOR PHYSICISTS, ENGINEERS AND CHEMISTS

Positions available for research work on nuclear batteries, dielectrics and gas diodes. For further information write or call Radiation Research Corporation, 140 East 59th Street, New York 22, N.Y., Plaza 1-3261.

#### **TRANSLATORS**

Translators of all European and Far East languages, in all branches of electronics, physics and engineering. Full time or free lance. Must be experienced specialists with fluency in English and given foreign language. Replies held confidential. Submit resume to: A.T.S., P.O. Box 271, East Orange, New Jersey.

#### ELECTRONIC DESIGN ENGINEER

Electronic Design Engineer, rapidly expanding Nuclear firm, excellent growth opportunity. Apply Nuclear Corporation of America, 196 Degraw St., Brooklyn 31, N.Y.

#### QUALITY CONTROL ENGINEER

Quality Control Engineer, rapidly expanding Nuclear firm, excellent growth opportunity. Apply Nuclear Corporation of America, 196 Degraw St., Brooklyn 31, N.Y.

#### TEACHING POSITIONS

Teaching Positions—Applicants needed for additional permanent staff in Electrical Engineering. Rank and salary commensurate with qualifications. Will consider one with only a B.Sc. E.E. if he is willing to work for an M.Sc. degree. Write Chairman, Department of Electrical Engineering, University of Nebraska, Lincoln 8, Nebraska.

#### ASSOCIATE PROFESSOR ELECTRICAL ENGINEERING

To teach graduate and undergraduate courses. Should have Ph.D., be 30 to 40 years old and be interested in one or more of the following: electromagnetic field theory, electron devices, network analysis servomechanisms. Salary \$9000 for 9 months. Opportunities to augment this through contact research to the extent of additional \$4500.00. Write Box No. 1057.

#### PHYSICAL CHEMIST OR PHYSICIST

Physical Chemist or Physicist with chemical background, BS or MS, experienced in solid state work for position in semiconductor research. Excellent working conditions with opportunities for graduate study. Location, nationally known research institution Western Pennsylvania. Detail education and experience first letter. Box 1058.

#### HEAD OF INSTRUMENTATION

For Newmont Mining Corporation's new geophysical exploration and development laboratory in Danbury-Ridgefield area Connecticut, Responsible for circuitry, design and construction of airborne and ground geophysical exploration and research devices in lower frequency ranges. Exacting but rewarding work toward increasing the world's resources. No governmental contracts or tie-ups are involved. Applicant should have EE, MSc or PhD and reasonable experience, Salary higher than normal rates, fully paid insurances and pension plan, opportunity for out-

(Continued on page 136A)



proudly announces

another milestone in growth,

professional career opportunities,

and advancement in research,

development and field engineering

in the military electronics industry.

GROWTH: Another modern, completely air-conditioned building is presently under construction in Plainfield, N.J. STAVID's new facility is 65,000 square feet and will be occupied in October, 1957. This increases our facilities to 150,000 square feet. STAVID is a young organization (12 years' old) and provides challenging, interesting work for its 950 employees. STAVID furnishes an excellent environment in which to bring out your best engineering talents.



CAREER OPPORTUNITIES: If you possess an E.E. or M.E. degree with a minimum of 3 years' experience, you can fulfill your career ambitions at STAVID in the following:

- FIRE CONTROL RADAR
- NAVIGATION SYSTEMS
- MICROWAVE
- ANTENNAS

- MISSILE GUIDANCE SYSTEMS
- TRANSISTORS
- SERVO-MECHANISMS
- TELEMETERING

ADVANCEMENT: In STAVID's dynamic, expanding organization, you will realize professional advancement with added responsibilities. You will be part of a team that utilizes the newest techniques known to man in advancing the state of the art.

Stavid

Write or Call For Appointment: Mr. James Clovis, Plainfield 7-1600, Extension 214

ENGINEERING, INC.

Route 22, Plainfield, N. J. Plainfield 7-1600



OFFICIAL U. S. ARMY PHOTOGRAPH

ARMY'S HAWK MISSILE, recently revealed, destroys attackers flying at even the lowest altitudes and in the blind zone of conventional radars. Raytheon is prime contractor with complete systems responsibility for HAWK—and for the Navy's new air-to-air Sparrow III.

#### To the one man in three who will qualify as a Raytheon engineer:

our small, versatile project groups are staffed with extremely capable engineers. This policy pays off exceedingly well for energetic, imaginative men who are looking for individual recognition with the challenge of responsibility and ready opportunity for advancement.

# Which of these interesting Situations with a Future is right for you?

As one of the world's fastest growing electronics companies with a record for history-making achievements, Raytheon is continually expanding. Interesting, rewarding openings for all types of engineers now exist in:

**COMMUNICATIONS (Commercial and Military)**—scatter, microwave relay, multiplex, mobile transistorized equipment.

**COUNTERMEASURES**—radar countermeasures equipment, advanced study projects.

RADAR (Pulse and CW Systems) — search, fire control, bombing, navigation, air traffic control, weather and commercial marine.

MARINE EQUIPMENT—submarine, ship, and airborne sonar, depth sounders, direction finders.

GUIDED MISSILES—prime contracts: Navy Sparrow III (airto-air), Army Hawk (ground-to-air).

**MICROWAVE TUBES** — amplitrons, magnetrons, klystrons, traveling wave tubes, storage tubes.

ELECTRON TUBES, SEMICONDUCTOR DEVICES, MAGNETIC COMPONENTS • MICROWAVE COOKING OVENS, ELECTRONIC INDUSTRIAL EQUIPMENT, ELECTRONIC MEDICAL EQUIPMENT

Raytheon plants are ideally situated for delightful suburban living in New England, California and Tennessee.

For the details you want, please write to Leonard B. Landall, Raytheon Manufacturing Company, Waltham 54, Mass. There's no obligation and your inquiry is completely confidential.

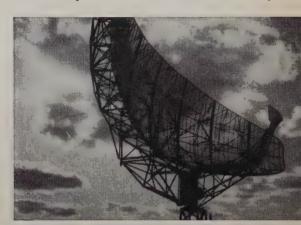
## RAYTHEON MANUFACTURING COMPANY WALTHAM 54, MASSACHUSETTS



#### Raytheon Engineering Opportunities



MICROWAVE & POWER TUBE engineers check operation of Raytheon microwave tubes in Air Force jet.



WAYLAND LABORATORY engineers developed this 40-foot L-band antenna to extend the range of radar.



**MAYNARD LABORATORY** engineers design and flight test airborne navigational and guidance systems.



MISSILE SYSTEMS DIVISION facilities include observation tower with radar tracking equipment.

#### The GENERAL Idea

ON ENGINEERING CAREERS



What?—digital computer techniques used in telephony?



Ferrite cores and other promising memory devices are being adapted for use in electronic telephone switching systems at General Telephone Laboratories.(Actual size

The engineer with a background in digital computer work is often surprised to find that, (A) the telephone industry offers a real opportunity for his specialized knowledge, and that (B) in telephony he is apt to face an interesting new challenge in terms of circuitry and high-speed switching operations.

At General Telephone Laboratories, we are making extensive use of computer technology to develop the telephone systems of tomorrow... as well as to solve the everyday problems of circuitry in existing systems.

We are, for instance, engaged in extensive research and development work on all-electronic, transistorized switching systems. An important phase of these projects involves memory devices. Existing techniques, such as ferrite cores, will require quite a lot of adaptation to meet the demands for speed imposed by electronic telephone switching. We are exploring every known technique of memory storage, including ferrite cores and photo memory devices, for both temporary and semi-permanent applications.

Electronic circuit design and packaging is another area where computer experience finds a valuable outlet at ratories, Northlake, Illinois.

General Tel Labs. In logical circuit design as applied to telephony, the engineer can apply his creative abilities to the fullest extent.

If the foregoing gives you some idea that telephony, far from being static, is one of the truly dynamic industries from an engineering standpoint, that's the way we intended it. At General Telephone Laboratories, our work ranges far beyond the telephone as such. Providing R&D support for Automatic Electric Company and the other affiliated manufacturing units of the General Telephone System, we work in the entire field of Communications and Controls.

#### Notes on growth...

Right about the time you read this, the General Telephone System will add its 3 millionth telephone, an increase of nearly 100% since 1950! Of interest to the engineer looking to his future is the fact that the General System's growth is rooted in one of the most stable businesses in our economy. This is a fact well worth considering, if your present job has more alleged glamour than stability.

#### You're invited ...

General Telephone Laboratories is expanding to keep pace with the healthy growth of the General Telephone System—not only its operating companies but its far-flung manufacturing operations as well. If you are qualified for important R&D assignments in electronics, electrical, electro-mechanical or mechanical engineering, we have a career opening that provides the hard-to-find combination of challenge and security. We'll be happy to give you the details about your specific opportunities. Write to Mr. Robert Wopat, President, General Telephone Laboratories, Northlake, Illinois.

#### GENERAL TELEPHONE LABORATORIES

NORTHLAKE, ILLINOIS

A member of the General Telephone System—One of America's great communications systems



(Continued from page 133A)

side courses at nearby universities as work permits, planned guest lectures. Country living within 60 miles of New York City. Apply Newmont Exploration Limited, R.F.D. 1, Danbury, Connecticut.

#### ELECTRONIC SALES ENGINEER

Electronic instrumentation, automation and nuclear equipment. Career opportunity for a competent graduate engineer or physicist with strong aptitude for sales (with or without sales experience) to join one of the fastest growing sales engineering organizations in the East. The position offers opportunity for creative sales work, with exceptional income potential and minimum supervision. Requirements: EE or Physics Degree with good scholastic record, exceptional personality and good appearance, plus maturity and enthusiasm. Age: 26-33, car required, Salary, commission and bonus. Please mail detailed resume. Box No. 1059.

#### TEACHING POSITIONS

Excellent opportunities are available in a new department. Location is at medium sized university in the midwest. Rank and salary commensurate with qualifications. Appointments are available beginning February, 1958 and September, 1958. Send complete resume to Box 1060.

## ambitious?

## OPPORTUNITIES WHICH LEAD TO MANAGEMENT

As an independent leader in the field of high permeability magnetics, we are expanding our creative engineering leadership. These are "threshold to management" positions for which we need

## ELECTRICAL AND ELECTRONIC ENGINEERS

Choose your own avenue of development or application work in instrumentation, magnetic circuitry and magnetic materials.

If you can qualify for a really bright future, send experience summary to

Mr. Keith Krewson, Mgr. of Personnel



BUTLER 4, PA. (near metropolitan Pittsburgh)



"MIMBUS," a new painting by the well-known team of science-artists Simpson-Middleman. In this work, the creators have found new artistic meaning in the Moon and its reflected light. An attempt to capture the polarized nature of moonlight is made. The result, an almost half-light, Collection of the Whitney Museum of American Art, New York.

#### Work in the world of supersonic flight—at Boeing

Supersonic flight is still in its infancy, and Boeing engineers are engaged in the adventurous task of pushing forward the frontiers of knowledge in this years-ahead world. Underway at Boeing are design projects for top-secret aircraft and missiles far more advanced than any yet developed. Related explorations delve into the required properties and capabilities of materials, fuels and systems not yet in existence. You'd find working on advanced Boeing projects a true adventure—challenging, rewarding, stature-building. Boeing offers this opportunity today to scientists, and to experienced engineers in many categories.

Drop a note now, to John C. Sanders, Engineering Personnel Administrator, Boeing Airplane Company, Department C-68, Seattle 24, Washington.



Leading Research Laboratory in Suburban Washington, D. C.

Several long range systems development programs have recently been awarded to Melpar, the execution of which require our engineers and scientists to pioneer into the no-man's-land of science. Of a highly advanced nature, these programs are vital to the Nation's defense and include weapons systems evaluation in a variety of fields and over 90 diversified projects in electronic R & D.

These long term assignments have created challenging openings which you are invited to consider. As a Melpar staff member you will become a member of a small project team charged with responsibility for entire projects, from initial conception to completion of prototype. Your advancement will be rapid, thanks to our policy of individual recognition, which promotes you on the basis of your performance, rather than age or tenure.

Wire or phone collect, or write to: **Technical Personnel Representative** 





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Openings Also Available at Our Laboratories in Boston and Watertown, Massachusetts.



#### By Armed Forces Veterans

In order to give a reasonably equal op-portunity to all applicants and to avoid overcrowding of the corresponding col-umn, the following rules have been

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

Address replies to box number indicated, c/o IRE, 1 East 79th St., New York 21, N.Y.

#### **ENGINEER**

Member IRE in England, of British nationality; age 29, married. Desires post in transistor, computer, or allied work. City and guilds London certificates in telecommunications. Experience: 2 years radio television, 2 years military electronics, 5 years radar. Present position experimental officer (electronics) 3 years, computer maintenance and management. Opportunity to earn American degrees desirable. Box 1000 W.

#### ADMINISTRATIVE ENGINEER

BS., MS. Presently Executive Vice-President medium sized electronic company. Familiar military sales, contract administration, manufacturing, equipment and systems engineering. Wright Field background. Box 1002 W.

#### ELECTRONIC ENGINEER

BS. Annapolis 1951, 1st class Radio Telephone and 2nd Class Radio Telegraph license, advanced amateur license. Currently working on Navy and Signal Corps radar, Lt., USNR 5 years active Naval service. 3 years in submarine force. Desires supervisory position in Los Angeles or Mexico area. Spanish interpreter. Box 1004 W.

#### **ELECTRONIC ENGINEER**

BSEE.; married; age 25. Available December 1957. 11/2 years experience as D&D engineer on microwave antennas and components for precision instrumentation radars. 2 years experience as Signal Corps contracting officer with thorough knowledge of military procurement, Desires position providing diversified engineering and management opportunities with growing company near eastern seaboard. Box 1005 W.

#### ELECTRONIC ENGINEER

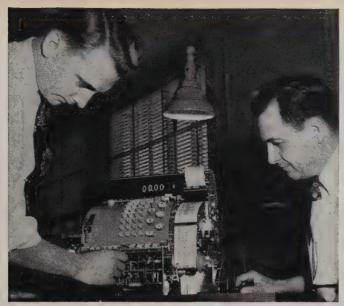
BEE. Georgia Institute of Technology 1954; age 27; married. 5 years service in U. S. Navy, released from active duty September 1957. Desires work in electronic circuit design. Desires southwest location. Box 1011 W.

#### **ENGINEER**

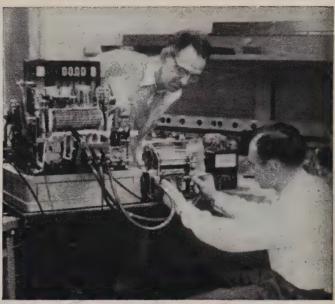
Physics and Education; BS. physics-math. 1948, MA. in education 1957. 1 year electronic experience. Will consider training or aide position in New York or Long Island area. Modest salary; married; age 33. Veteran Army Signal Corps. Box 1012 W.

(Continued on page 140A)

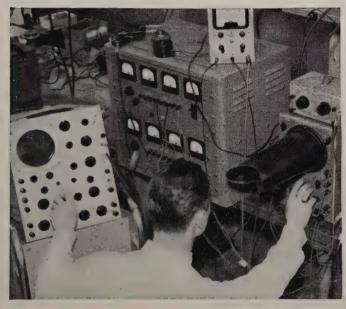
138<sub>A</sub>



**MECHANICAL ENGINEERS** are using their skills in the design and development of new mechanisms required for business machines and for those mechanical products which are associated with electronic data processing equipment.



**ELECTRO-MECHANICAL ENGINEERS** are constantly faced with the problems of capturing information from the various input devices and converting this information into a usable form for subsequent use in data-handling equipment.



**ELECTRONIC ENGINEERS** enjoy an unparalleled freedom in the development of new types of circuitry and components which are necessary to maintain leadership in the competitive field of record-keeping automation.



**COMPUTER ENGINEERS** backed by the company's computer research since 1938 are developing an economical, flexible digital computer to meet the requirements of all record-keeping applications.

## ENGINEERING UNLIMITED

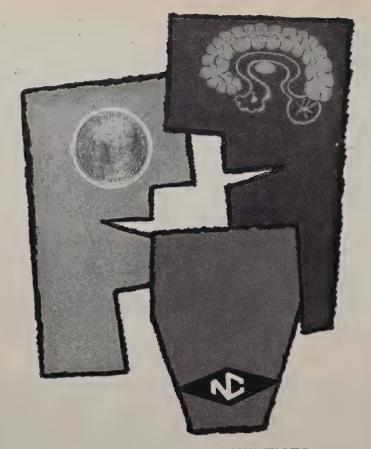
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If you are looking for a challenging opportunity with an established company which has tripled its sales in ten years—one that offers excellent starting salaries as well as permanent positions...

Act at once! Send resumé of your education and experience to Employment Department, Technical Procurement Sec. R, The National Cash Register Company, Dayton 9, Ohio.



PROCEEDINGS OF THE IRE October, 1957



ENGINEERS & SCIENTISTS

## WE CAN OFFER YOU THREE THINGS:

HARD WORK

GOOD PAY

NATIONAL'S REPUTATION

That the work is hard, the record shows. It's difficult enough to develop a workable concept of harnessing atomic resonance for frequency control, but it's harder still to engineer the concept into a practical, reliable apparatus like the Atomichron—a unit with a stability of 1 in 10<sup>10</sup>.

That the pay is good, the record shows, too. For one doesn't keep some of the best minds in electronics with promises. Men who develop high information density receivers of the sort that are used in astrophysics and geodesy find very tangible rewards at National.

As for reputation, National has maintained one for good engineering and fine craftsmanship in electronics since 1914. And anyone familiar with scatter systems and signal processing equipment knows that National isn't content simply to rest on laurels.

If you're one of the rare ones, to whom such things are sufficient reward—if you're interested more in the solidity of good work than in a parklike atmosphere or walnut desks—and if you have the courage and the ability to tackle some of the most difficult and intriguing problems in modern physics and electronics, then you owe it to yourself to contact National.

Send your resume today to F. M. Swope. It will be read by engineers and you will get a reply from an engineer.



NATIONAL COMPANY, INC.

61 Sherman Street . Malden, Mass.



#### By Armed Forces Veterans

(Continued from page 138A)

#### DIGITAL COMPUTERS

BSEE; graduate work. 6 years experience with electronic circuits and systems utilizing transistors and tubes in pulse applications. Presently Project Engineer. Desires responsible technical work in the field of digital devices for business and industrial application. Box 1014 W.

#### ELECTRONIC ENGINEER

BSEE. Physics 1951. Experienced in pulse circuits, including digital data handling, radar simulation, radar presentation. Systems experience in MTI and automatic test equipment for missile guidance. Desires northern New Jersey or southern Connecticut area. Box 1015 W.

#### ENGINEER

Age 28. No degree. 10 years diversified electronics experience including Armed Forces as technician and practical engineer. Speak, read and write Spanish fluently. Presently located in Mexico. Desires position as field engineer or technician in Latin America with responsible firm, Box 1016 W.

#### MANAGEMENT OR SALES ENGINEERING

Broadcast/television or ancillary fields are where my abilities will be most useful. Presently director of engineering and general manager of

(Continued on page 142A)

#### PHYSICISTS ENGINEERS MATHEMATICIANS

Opportunities for varied and interesting work in

## OPERATIONS RESEARCH WEAPONS SYSTEMS ANALYSIS

Professional advancement through broader experience for individuals who have done successful and creative work in particular technical fields such as microwaves, servo theory, digital computers and data systems, and who wish to obtain more comprehensive experience.

Small informal organization administered by scientists where technical excellence, energy, and creative ability are encouraged and rewarded.

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G. C. DEWEY & CO., INC. 19 W. 44th St., N.Y. 36, N.Y., MU 2-7369

## frame of reference

The chart below is a simplified representation of 11 different staff member fields at Sandia Corporation. You might call it an occupational frame of reference, within which are located the many activities involved in our work—design

and development of nuclear weapons for the Atomic Energy Commission. In each of the 11 fields, challenging positions are available for qualified engineers and scientists at all degree and experience levels.

	ENGINEERING	PHYSICS	MATHEMATICS
Applied Research			
Weapon Systems Engineering			
Component Development			
Electronic Development			
Handling Equipment Design			
Standards Engineering			
Quality Assurance and Surveillance			
Environmental Testing			
Field Testing			
Manufacturing Relations Engineering			
Military Liaison and Field Engineering			

There are many other things you'll want to know about Sandia Corporation. You'll be interested in our extremely liberal employee benefits. You'll want to know about the advantages of working and living in Albuquerque, famous for its healthful year-round climate and recreational attractions. You'll want information on schools, homes, and cultural facilities. And you'll want to know more about our work, and our back-

ground as a research and development laboratory. Our illustrated brochure answers these questions, and many others. For your copy, please write to Staff Employment Section 554A.



## ELECTRONIC ENGINEERS

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California
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Radar
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Optical
Telemetering
Data Reduction
Antenna

Work entails research and development to production stages in the above fields, also, inertial systems, magnetics, and microwave.

All benefits including paid life insurance and pension plan. Company pays our fees also liberal travel and moving expenses.

Please mail three copies of your resume in confidence to:

Harry L. Brisk, Mem. I.R.E.

### ACCREDITED PERSONNEL SERVICE

12 So. 12th Street

Philadelphia 7, Pennsylvania



#### By Armed Forces Veterans

(Continued from page 140A)

two small radio and TV stations. Was previously consulting registered professional engineer Washington, D.C.; first phone and amateur licenses; BS; also Kentucky Colonel. Engineering covers broad frequency allocations work; AM, FM, TV, station planning and building; commercial transmitter design. Administration covers station and corporation management; selling tangibles and intangibles; director of large technical education institution; author of scores of technical articles and papers, and three books. Box 1018 W.

#### ELECTRICAL ENGINEER

BEE, CCNY, Jan. 1953, 4½ years experience in analog computer simulation on a variety of problems. Military experience included 8-month radar course plus analog computer simulation. 9 credits needed to complete masters degree at Columbia University. Therefore, necessary to remain in New York City area. Box 1019 W.



(Continued from page 128A)

#### Automatic Machine Tool Control

Wang Laboratories, Inc., 37 Hurley St., Cambridge 41, Mass., announces the design, development and completion of the first Weditrol, a numerically controlled machine tool con-

trol system.

The first model recently delivered, was specially designed to control a production lathe with a cutting speed approximately 100 inches per minute, and a minimum incremental distance of 0.0002 inches. The system is so designed that it can be easily be adapted to three dimensional control on other types of machine tools.

The Weditrol

gets its commands from a punched paper tape and develops the control. The repetition rates of the pulses are so proportioned that their simultaneous control of the X and Y direction will cause the table to travel the desired path. All the programmings are generated internally and require no special computers to generate the pulses. A fairly short paper tape is sufficient for most of the cutting processes, but Weditrol is adapted to other types of input such as the punched card. Weditrol has a slow approach system so that when the cutting approaches the end of the stroke it slows down automatically to prevent overshot of the servo system.

(Continued on page 144A)

#### ELECTRONIC ENGINEERS

Immediate
Openings
at Sylvania's
Buffalo
Engineering
Laboratory

SPECIAL CIRCUITS

Requires development of new section within our Advanced Development Department. Must be capable of inventing practical circuits which will demonstrate the feasibility of new theoretical concepts in the field of communications. Advanced degree preferable and about 10 years experience required.

#### COMMUNICATIONS SYSTEMS

Requires ability to develop and direct applications of new techniques to existing and newly developed communications systems such as radio, radar, sonar and radio teletype. About 10 years experience required.

#### FIELD ENGINEERING

Opportunity for graduate electronic engineer to learn design of complex electronic system and to follow through in field. Eventual locations Fort Worth, Texas and Dayton, Ohio. B.S.E.E. and 5 years experience in electronic field engineering required.

#### MICROWAVE ENGINEERING

Requires carrying of antenna-radome design through prototype release. We are looking for an engineer with 10 or more years experience as well as less experienced candidates.

Please send your resume to Engineering Personnel Dept.

Electronic System Div.



175 Great Arrow Avenue Buffalo 7, New York

#### MOUNTAIN VIEW, CALIFORNIA

#### **▶** Reconnaissance Systems Laboratory

Newest of Sylvania's Mountain View facilities offers opportunities for research, development and fabrication of military electronic reconnaissance systems for detection and surveillance of electromagnetic radiation in and around the earth.

#### ► Electronic Defense Laboratory

Research, development and fabrication of electronic countermeasures systems and equipment.

#### ► Microwave Physics Laboratory

Research and advanced development in guided microwave control devices utilizing ferrites, gaseous electronics, ferroelectrics and paramagnetic resonance.

#### ▶ Microwave Tube Laboratory

Research, design, development and production of Klystron, Traveling Wave tubes and Backward Wave oscillators.

Openings in the following fields:

- Operations Research
- Guided Microwave Devices
   Research & advanced
   development
- Systems Analysis
- Systems Development
- Design & Development

  Transmitters, receivers, components, antennas
- Data Handling
- Electronic Packaging
- Field Engineering
- Mechanical Engineering
- Microwave Tubes
   Research, design & development

For further information on these West Coast opportunities, send your resume to

J. C. Richards
P.O. Box 1296
Mountain View, Calif.

#### **ENGINEERS and SCIENTISTS**

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Men
for Advanced
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Research and
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in East
and West
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Locations

East or West, Sylvania Laboratories are in the forefront of advanced electronic research and development, offering positions to men capable of important scientific contributions...and interested in the rewards this growing company offers for creative work.

Salaries are entirely commensurate with background and ability. Benefits are broad, and include ample provision for graduate study. Opportunities for growth are genuine.



#### WALTHAM, MASSACHUSETTS

#### ► Missile Systems Laboratory

Openings for senior men in weapons systems analyses, design, development & management.

- High Power Radars
- Electrically Scanned Antennas
- Missiles & Guidance.
- Operations Research
- Information Theory
- Data Processing
- Electronic Physics

#### ► Avionics Laboratory

- Electronic Systems Design
   & Development
- Microwave & Antenna Research
   & Development
- Electronic Packaging & Test Design
- Computer Systems Engineering
   & Logical Design
- Technical Coordination & Liaison

#### ► Applied Research Laboratory

- Operations Research
- Communications Theory
- Automatic Controls
- Airborne Interceptor Radar
- Radar Simulators
- Missile Electronics



For further information on these East Coast opportunities, send your resume to

> Graydon A. Thayer 100 First Ave., Waltham, Mass.

#### **OPERATIONS RESEARCH ANALYST**

We are seeking a particularly creative individual with a Ph.D. or M.S. and equivalent experience, possessing research experience in Mathematics or Mathematical Statistics plus practical knowledge of high speed computers to develop analytical methods and models for solution of military and non-military Operations Research problems for a challenging assignment in our Operations Research Group.

Current activities of this Group include:

- 1. A study of digital computer techniques for simulating air traffic and air traffic control procedures.
- 2. An investigation of properties of communication networks through digital computer simulation of systems of interest.
- 3. Research concerned with methods for prediction of traffic distribution over road
- 4. Development and evaluation of optimum path selection techniques for finding the shortest or least cost path through a maze.
- 5. Research studies of data processing requirements and techniques for major commercial and military operations.
- 6. Analysis of hospital service operator functions to improve doctor paging and sign-in procedures.
- 7. Multivariate statistical analysis of physical and biological systems, with particular emphasis on design of experiments.

This position offers unusual freedom of activity and diversified opportunity to the man who wishes to fully utilize his creative ability.

As a leading independent research organization, we offer competitive salaries, excellent benefits and generous relocation allowance.

Send complete resume to: A. J. PANERAL

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A Division of

**GENERAL DYNAMICS** CORPORATION



#### Engineers or Physicists

experienced in semiconductor device technology will find a challenging interest in our program of transistor and diode study. Accelerated use of semiconductor devices in developmental projects, governmental and civilian, requires broad knowledge of device design and type capability. Evaluation of current types and future projections are elements of this solid state study program.

Send résumé to:

ARTHUR N. PAUL

Director of Technical Personnel

A Division of General Dynamics Corp. 1412 N. Goodman St., Rochester 3, N.Y.



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 142A)

#### Rixon Electronics Becomes Independent

Rixon Electronics, Inc., a research and development firm located in Silver Spring, Maryland, has become an independent company, with James L. Hollis as the new president. Rixon was formerly a subsidiary of Page Communications Engineers, Inc., Washington, D. C. The change was made through a stock transfer transaction in which Hollis relinquished his interest and resigned as an executive in the Page corporation.

Organized primarily for the purpose of developing ing and producing prototype models of electronic equipment, Rixon has designed and produced equipment ranging in size from small uhf miniaturized low noise preamplifiers to 60-



kilowatt vhf transmistters. Starting with three employees when first organized five years ago, the firm now employs over 100 people.

Most of the efforts to date have been concentrated on specialized equipment for use in "scatter" communications. Special purpose test and monitoring equipment, antenna preamplifier stages, special purpose exciters and various components of terminal or interconnect equipment developed are in service today in important scatter communications circuits.

Two major successful developments are the TX-264 60 kw vhf transmitter and the MUX-16 (AN/TCC-35) Sixteen Channel Teletypewriter Multiplex System. Both were developed under contracts with MIT Lincoln Laboratory and Page Communications Engineers; and prototypes are now in service in Department of the Air Force installations.

#### 500 MC Power Tubes

Electron Tube Div. Radio Corporation of America, 415 S. 5 St., Harrison, N. J. announces the  $7034/4 \times 150A$  and 7035/4×150D, small and compact forced-aircooled beam power tubes designed for service at frequencies up to 500 mc. They are useful as af power amplifiers and modulators, wide-band amplifiers in videoapplications, linear rf power amplifiers in single-sideband suppressed-carrier equipment, and class C amplifiers or oscillators. These new types have a maximum platedissipation rating of 250 watts which is made possible by a specially designed, high efficiency radiator that is hard soldered to the plate for better heat transfer.

(Continued on page 146A)

York, Penna.

## TO MAKE THINGS BETTER FOR AMERICA—

Avco Manufacturing Corporation is a builder of quality products for the commercial economy and high-performance military systems for national defense. Aircraft engines, electronics systems, farm implements, kitchen components and the nose cone for the Air Force Titan intercontinental ballistic missile are being produced by Avco today.

The foundation for Avco tomorrow is being laid at our Research and Advanced Development Division. We know that the technology of the future will be built on scientific research being done now. Amazing new materials and new means for creating useful power hold out the promise of great advances in transportation, in agriculture, in consumer products, in nearly every aspect of our future economy. New scientific knowledge and its imaginative application can turn these promises into reality. Work at the Research and Advanced Development Division has already shown what rapid strides can be taken in a short time.

The division is composed of outstanding scientists and engineers who work in an environment that fosters creative investigation. It is the "breakthrough" division of a progressive manufacturing organization. Avco management recognizes the role of the scientist in modern technology. Avco's determination to make things better for America places the resources of a large, diversified, aggressive company firmly behind the Research and Advanced Development Division.

Raymond A. Rich
President, Avco Manufacturing Corporation





Raymond A. Rich, President, Avco Manufacturing Corp.



Pictured above is our new Research and Development Center now under construction in Wilmington, Massachusetts. Scheduled for completion in early 1958, this ultramodern laboratory will house the scientific and technical staff of the Avco Research and Advanced Development Division.

Avco's new research division now offers unusual and exciting career opportunities for exceptionally qualified and forward-looking scientists and engineers in such fields as:

#### Science:

Aerodynamics • Electronics • Mathematics • Metallurgy Physical Chemistry • Physics • Thermodynamics

#### Engineering:

Aeronautical • Applied Mechanics • Chemical • Electrical Heat Transfer • Mechanical • Reliability • Flight Test

Write to Dr. R. W. Johnston, Scientific and Technical Relations, Avco Research and Advanced Development Division, 20 South Union Street, Lawrence, Massachusetts.

### SENIOR RESEARCH PHYSICIST SENIOR ELECTRONICS ENGINEER

The new Central Research Laboratory of Continental Can Company has several opportunities for versatile scientists and engineers with advanced degrees and industrial experience to pioneer in the application of acoustics, optics, mathematical physics, electronics, rheology, solid state physics, and other fundamental fields to long-range industrial problems in such areas as energy conversion, automatic controls, instrumentation, and communications.

The wide variety of materials manufactured or fabricated at high speeds by Continental includes metals, glass, plastics, paper, fiber, and combinations of these, and provides opportunities for advancing knowledge in many new fields. Research facilities of the Company's new Chicago laboratories are believed second to none, and are located so as to allow staff members to live in some of the finest western and southern suburbs of the city. Proximity to the John Crerar Library, Armour Research Foundation, the University of Chicago, Argonne National Laboratory, and many leading manufacturers of scientific and technical equipment enhances professional development and expedites accomplishment in chosen fields.

Staff members will be granted the full degree of individual recognition attainable in a total staff of 100 covering the fields of chemistry, metallurgy, engineering, and physics, and will have the opportunity to work closely with scientists and engineers in the other fields. Salaries and other benefits meet the highest industrial standards.

Please write, giving a brief resume of qualifications, to Director Physics Research, Central Research and Engineering Division, Continental Can Co., 7622 S. Racine Avenue, Chicago 20, Illinois.

#### ELECTRONIC ENGINEER

Circuit Design & Product Development For Systems Involving

- . . . Data Transmission
- . . . Coding Devices
- . . . Remote Control
- ... Transistor Application

Requirements: Imagination, I to 5 years of circuit design experience, an engineering degree or equivalent.

Non-Government-Responsibility-Rapid Advancement



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Longacre 5-1300



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(Continued from page 144A)



The 7034/4×150A and 7035/4×150D are unilaterally interchangeable with the older types 4×150A and 4×150D, respectively. At frequencies up to 150 mc, they have a higher plate-voltage rating and thus can provide substantially higher power output at such frequencies.

The heater in the  $7034/4 \times 150A$  operates at 6 volts /2.6 amperes, and that in the  $7035/4 \times 150D$  at 26.5 volts/0.58 ampere. These new types have an overall length of  $2\frac{3}{8}$  inches, a diameter of  $1\frac{5}{8}$ 

inches, and weight 4 ounces.

#### Noise Generator

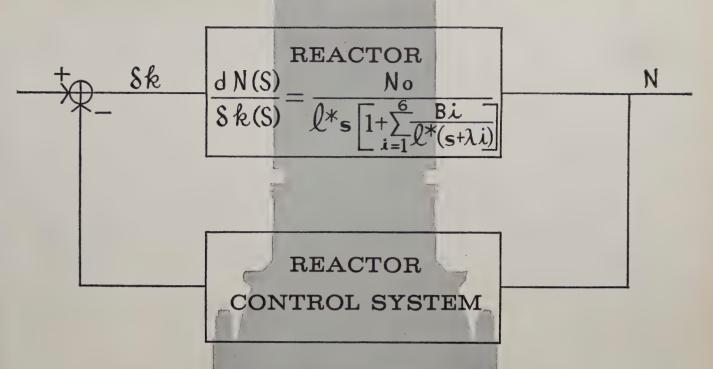
Electronic Noise Generator Co., P.O. Box 45344, Los Angeles 45, Calif., offers the new Model 301 Low Frequency Gaussian Noise Generator. The Model 301 Noise Generator makes available a random voltage source with a spectral density which is automatically controlled to  $\pm 0.1$ db from 0 to 35 cps and a Gaussian amplitude distribution with an accuracy of better than 1 per cent. Maximum output voltage is 15 volts RMS.



This precision noise generator design has been extensively used with analog computers to study the effects of random disturbances on fire control systems, guided missile systems and airframe structures. It has also proved its usefulness in statistical computer studies of problems in the fields of biology, meteorology and oceanography.

Models 201A and 401 are handled exclusively by Electronic Associates, Inc., and Reeves Instrument Corporation, respectively.

(Continued on page 148A)



## Control Engineers Develop New Methods of Control and Analysis

Using standard servo-mechanism techniques, electrical engineers at Bettis Atomic Power Division design and develop control systems for nuclear power plants. For example, the above diagram illustrates the basic transfer function for a nuclear reactor showing the number of power producing neutrons as a function of control rod motion.

The work of the nuclear control engineer encompasses a wide range of engineering skills since he must acquire and apply a general knowledge of an entire nuclear power plant and a detailed knowledge of reactor dynamics. Because of the analytical nature of nuclear design, it is the control engineer who determines many of the basic plant parameters and operating limitations. The techniques he employs are very similar to conventional feed-back control and regulating system design practices as well as the utilization of techniques specifically developed for the atomic energy field.

Because of the rapid advancements in reactor design and technology, the control engineer is continually expected to develop new methods of control and analysis. His work is made even more important and interesting by such unique requirements as 100% fail-safe design, stringent component response times, and the use of all static components. It is, in fact, the responsibility of the nuclear control engineer to determine what part of the almost unlimited power available from a nuclear reactor can be safely harnessed and controlled for use by present commercial power machinery.

We welcome inquiries from electrical and control engineers interested in the excellent careers offered by one of the leaders in the new and growing nuclear power industry. Please send your résumés to: Mr. M. J. Downey, Bettis Atomic Power Division, Westinghouse Electric Corporation, Box 1468, Dept. A-185, Pittsburgh 30, Pa.

Westinghouse



## PILOT tweed PROPHET BY CORNELL AERONAUTICAL LABORATORY

Six years ago, the Bureau of Ships asked C.A.L. to make a feasibility study of *automatic*, all-weather control of aircraft in return-to-carrier operations. ACCA (Automatic Carrier Controlled Approach) is our name for the project. One of the most complex phases of the project was the *electronic prediction* of a ship's movements and the subsequent use of these predictions in the total physical system.

Over the years, by combining our manpower resources in electronics with knowledge in such fields as control theory, computers, meteorology, aerodynamics, statistical analysis and information theory, we have continued to assist in making major decisions on the techniques and equipment involved. Theoretical and analytical studies have been supplemented by key experiments conducted in the Laboratory, in the air, and on the high seas.

The ACCA project is typical of the intensely interesting opportunities at C.A.L. for men capable of mentally moving forward the frontiers of scientific knowledge.

#### **ORNELL AERONAUTICAL LABORATORY, INC.**

OF CORNELL UNIVERSITY



The story of Cornell's 160 current projects and those preceding them is contained in a 68-page report, "A Decade of Research." Whether you are interested in C.A.L. as a place to work or as a place to watch, you will find "A Decade of Research" both useful and pertinent, Mail the coupon now for your free copy.

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(Continued from page 146A)

#### Johnston Appointed by Advance Industries

Robert L. Johnston, Colonel USAF retired, was named Assistant to the President at Advance Industries, Inc., 640 Memorial Dr., Cambridge, Mass., it was announced today by J. E. Ashman, President.

Colonel Johnston brings to his new post an extensive background in administrative, research, development and engineering experience. His assignment just prior to retiring on June 30, was Deputy Director of Research and Develop-



R. L. Johnston

ment at the USAF Headquarters in Washington, D. C. where he previously served as Technical Executive and Assistant Director successively.

Actively engaged in USAF Research and Development since 1945, other assignments included: Chief of the Armament

(Continued on page 150A)

#### OPPORTUNITIES for Electrical Engineers and Physicists in Industrial Automation

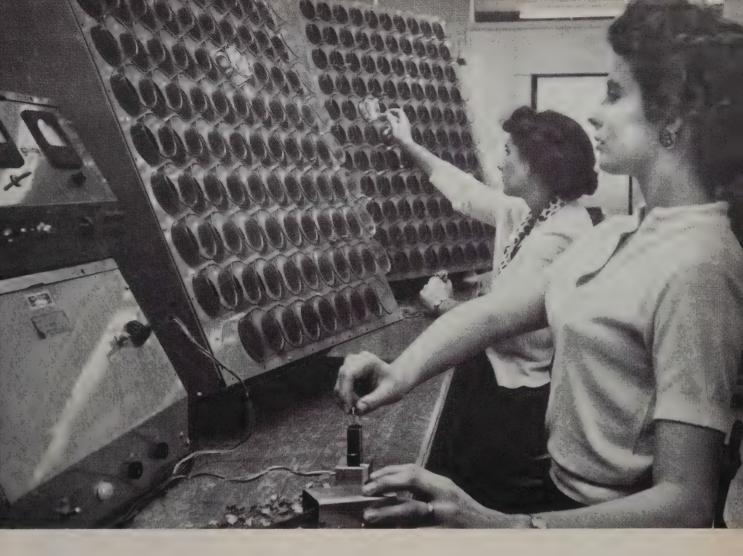
FMC Central Engineering's current expansion into automatic measurement and control field provides unusual opportunities for technical accomplishment on important company sponsored long range programs. There is need for both systems engineers and specialists.

Qualified applicants including recent graduates are invited to write:

Manager of Central Engineering

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Homely articles like water glasses and light bulbs are used in this automated selector built by TI mechanization engineers. Now, non-technical TI-ers close a circuit with a transistor just off the production line; wait a second for the circuit to evaluate it; then pop the unit into the glass that lights up. This "matching" operation is another advance toward automation of semiconductor manufacture ... to free technical personnel for other important duties ... to help Texas Instruments produce more electronic components and apparatus at lower cost.

This special application is typical of the many special engineering opportunities now open at Texas Instruments ... openings for industrial engineers, machine designers, automation engineers, and other specialists to fill a continuing need to develop the mechanics for making things that have never been made before. Eighty per cent of today's TI products are new to its production lines within the last 3 years.

You are invited to join one of the many expanding programs at 27-year-old Texas Instruments... where recognition of individual achievement has contributed to TI's twentyfold growth in the last ten years — to a current

\$70 million volume. Advanced personnel policies include company-sponsored educational assistance, profit sharing, insurance, and retirement programs.

Texas Instruments plants are within Dallas, yet away from downtown traffic... within 5 minutes of fine residential areas, churches, and public and private schools. Your home will be within 15 minutes of year-around recreational, amusement and cultural activities.

SEMICONDUCTORS AND OTHER COMPONENTS — Design engineering, industrial engineering, production coordination, product evaluation, mechanization for making transistors, diodes, rectifiers, resistors, panel instruments. Write W. C. Spaller.

ELECTRONICS AND ELECTROMECHANICAL APPARATUS – Radar, sonar, infrared, navigation, magnetics, telemetering, communications, computers, transformers. Write R. E. Houston.

RESEARCH – Ph.D. level for research: semiconductor materials and devices, ferromagnetics, infrared, high speed data reduction, etc. ADMINISTRATION – Engineers for: production, planning, purchasing, cost analysis, etc. Write W. D. Coursey.

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Admiral's commanding lead in certain broad areas of military and civilian electronics has created a number of challenging opportunities. Match your special interests and past experience against the following check list.

**COMMUNICATIONS**—Design of airborne, automatic tuned communication systems.

**COUNTERMEASURES**—Design work in systems and equipment in a wide range of techniques.

RADAR—X band fire control. L band identification.

**MILITARY TELEVISION**—Receiver and transmitter design. Camera design. Transistor applications.

PALO ALTO RESEARCH—Development of new technologies opens door on a program of advanced research in aeronautical electronics. Experienced and intermediate level engineers send resume and salary requirements to R. M. Jones, Admiral Corporation, 901 California Ave., Palo Alto, Cal. . . . for California openings only.

Current openings offer excellent income and opportunity for rapid advancement. Complete employee benefit program includes retirement plan, paid group insurance, college tuition refund plan and ideal working conditions. On-the-job training for junior and intermediate engineers. Write, summarizing your education and experience to John Harlan, Personnel Division.

### **Admiral Corporation**

3803 W. ARMITAGE AVE., CHICAGO 47, ILL.



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(Continued from page 148A)

Laboratory and Deputy Chief of Engineering Division, Operations, Air Materiel Command. Johnston conceived and organized the Weapons Systems Division, Wright Air Development Center, and served as Chief of this responsibility.

#### TV Camera Kit Bulletin

Electron Corp., 5512 Dyer St., Dallas, Texas, announces a new TV camera kit, priced at \$395.00 for closed circuit operation. A useful tool for industry, education, medicine, the police and military, the camera may be used with a monitor or standard TV receiver. This literature is available on request to the firm.

#### **Automatic Sorter**

Strempel Instrument Corp., Lake George, N. Y., has developed two reliable, unattended Resistance Sorters for component and equipment production. Type R-1A for axial lead resistors and Type R-1B (shown) for capped or no-lead resistors, are now available from the firm.

(Continued on page 152A)

#### ELECTRONIC ENGINEERS

## a FUTURE



IFI—a young, rapidly expanding organization that has doubled its size the past year, offers unusual, interesting and challenging opportunities on all levels to Electronic

Engineers with circuitry and equipment design background or applicable experience to work on UHF and VHF systems. Wide band knowledge particularly desired.

As a member of an IFI project, you'll have opportunity to improve your technical knowledge, enjoy freedom and a team spirit found only in a young organization of our size.

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Mechanical, Electrical, Physicist For engineering and development of advanced airborne navigation systems and related test equipment.

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### **Physicists**

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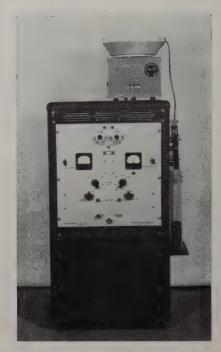
Call Mr. Becker at ORegon 7-8400 or write

INDUSTRO TRANSISTOR CORPORATION 649 Broadway, New York 12, New York



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(Continued from page 150A)



Parts are sorted at 4,000 pieces per hour into "Acceptable," "High" and "Low" groups. Standard machine has dc bridge measurement with 2 volts across the part, independent setting of High and Low tolerance limits from 0.5 per cent to 20 per cent with accuracy of sorting at the limits of ±0.2 per cent. Special voltages, higher accuracies can be supplied; reel pack and strip pack fixtures are available.

#### Rectangular-Wave Generator



The Model RWG-8A rectangular-wave generator, manufactured by Elcor, Inc., P.O. Box 354, McLean, Va., is the first of a line of modular instruments with selfcontained power supplies for operation directly from 117 volts 60 cps ac. Featuring output rise and fall times of 0.25 microsecond, this instrument converts a sine wave or any other periodic waveform into a rectangular wave of the same frequency. Alternatively upon the flick of a frontpanel switch, a rectangular wave at the power-line frequency is generated. Two Model A105-15A Isoplys are employed in a unique direct-coupled discriminator circuit that provides an eight-volt zero-based negative-going output signal at low im-

(Continued on page 154A)



## **Electronics Engineers—**

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Your opportunities for personal and professional growth at Stromberg-Carlson are as big as your own initiative.

First, you'll get the recognition you deserve as a professional engineer. You'll advance fast because the company is growing fast (5-fold expansion since 1942).

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Openings are now available for Electrical Engineers, from junior to senior engineering levels, in the fields listed at the right. Specialized experience desirable in transistorization, sub-miniaturization, and advanced circuitry.

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ARTHUR N. PAUL, Director of Technical Personnel



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DIVISION OF GENERAL DYNAMICS CORPORATION

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U.S. Citizenship. EE, ME, Physics, Math degree. One to five years' experience. A desire for technically demanding and stimulating work.

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GENERAL & ELECTRIC

Court Street, Syracuse, New York

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These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 152A)

pedance. Optional features include an amplitude control and variable output bias. Case dimensions are 13×8×81 inches, with a  $1\frac{3}{4} \times 9\frac{1}{2}$  inch front panel for mounting in a standard half-width relay rack. Other modular units with the same size and general appearance as the unit shown include a wide-band decade dc amplifier, flip-flop, binary scaler, gated oscillator, and pulse generator. The selfcontained power supply feature provides a maximum of convenience and a minimum of interaction when various modular units are interconnected to make a complete system. The complete instrument weighs three pounds and two ounces.

#### Speech Transmission Analysis Equipment

New equipment designed at Bell Telephone Laboratories and developed by the Modac Div., Airborne Instruments Laboratory, Thornwood, N. Y., now permits Bell researchers to prove complex theories of speech transmission without building expensive test models.

(Continued on page 156A)

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It is a field of major effort at Lockheed, with emphasis placed on new approaches and techniques. Activities cover all phases of information processing.

This expanding effort has created a number of new positions for highly qualified scientists, mathematicians and engineers. Key supervisory positions are among those open. Fields of interest include:

- Logical design
- Circuit design
- Information processing systems analysis and synthesis
- Component development

Those possessing strong ability and experience in this field are invited to write the Research and Development Staff at Sunnyvale 10, California.





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Although engineering openings still make headlines across the country, the unvarnished truth is that all the positions offered to qualified engineers do not assure the kind of security and professional, progressive future an applicant has a right to expect or demand. Recent localized situations and events have brought this job security and job opportunity situation into sharp focus for many today.

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SOLID STATE PHYSICS MICROWAVES & ANTENNAS

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(Continued from page 154A)



Bell Laboratories researchers developed a theory they considered might eliminate the setting up of costly and time consuming masses of experimental equipment. If they could get a piece of equipment that could convert their theories into computer information, a great saving of time and money could be effected. As a result, the Record and Playback Unit was conceived and is being manufactured by Modac. This equip-

(Continued on page 158A)

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Today as Manager of Ordnance Engineering, Harry Ellerman is characteristic of the group of brilliant engineers whose outstanding achievements have materially contributed to the reputation Westinghouse-Baltimore enjoys as a leader in the electronics field.

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(Continued from page 156A)

ment reduces experimental theories on speech and speech systems to a magnetic tape and evaluates them by actually examining electrically the synthesized output of an IBM computer, as different variables and engineering concepts are introduced.

Joseph D. Mountain, Director of Modac, in explaining the equipment, stated "The theory testing system couples Modac's Magnetic Tape Record and Playback Unit with a high-speed electronic computer. In sound research, exact conditions of the proposed telephone circuitthe functions of the existing equipment plus the individual function of the equipment to be introduced—are fed onto magnetic tapes that record all of the functions as electronic impulses. The Modac equipment together with a converter combines the impulses into digits, which it feeds to the computer. In the computer, the digits are run through a myriad of equations simulating the circuit, and a final answer in numerical form—is produced. This answer is then fed back into Modac Equipment where it is converted into electronic impulses which exactly duplicate those of the proposed new circuitry. The machine then reproduces the voice through a speaker, exactly as it would sound if the voice had traveled any proposed distance."

#### Check Chart of Lampholders and Indicator Lights

Drake Manufacturing Co., 1711 W. Hubbard St., Chicago 22, Ill., has just released a new check chart of official style numbers of Lampholders and Indicating Lights for military applications, with the corresponding Drake catalog numbers for each.

The chart is designed to make it easier for Military contractors and subcontractors to make accurate selection of the correct Miniature Lighting units to meet military specifications.

#### Panel Instrument Bulletin

A bulletin covering the group of long scale panel meters for specialty applications has just been issued by the Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 12, N. J. Weston is a subsidiary of Daystrom, Inc. Instruments are available in sizes from  $2\frac{1}{2}$  to  $5\frac{1}{2}$ inches for a wide range of current and voltage indications as well as tachometry and temperature applications. In addition to long, readable 250° scales, these instruments are said to have excellent ballistic characteristics and provide higher accuracy and improved sensitivity. Instrument movements are rubber mounted for shock resistance and embody springbacked jewel construction. Copies of this bulletin may be secured direct from the manufacturer.

(Continued on page 162A)



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(Continued from page 158A)

#### Telemetering Oscillator

Dorsett Laboratories, Inc., 401 E. Boyd St., Norman, Okla., recently announced an innovation in voltage controlled telemetering oscillators; the "Little Jewel," less than half the size of previous models, features one-hundredth the power



requirement of the smallest VCO formerly available yet has improved stability and linearity. Employing subminiature tubes and printed circuitry, nine plug-in oscillators, and operational mixer, and a self contained power supply are all packaged in a unit less than 0.09 cubic foot. Power

(Continued on page 164A)

## RESEARCH PHYSICIST

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(Continued from page 162A)

requirement per oscillator is 30 milliwatts and linearity is  $\pm 0.5$  per cent of F.B.W. while drift is held to less than  $\pm 3$  per cent.

The Model O-15 oscillator is available on all standard RDB channels; either 7.5 per cent of 15 per cent deviation. Packaged together in one rack approximately 4×4 ×9 inches are nine oscillators of any frequency combination, a mixer, and a battery supply capable of continuous operation for 15 hours. Optional is a 400 cps power supply. Oscillator input is high impedance and output of the mixer is adjustable 0 to 3 volts, sine wave with less than 1 per cent distortion.

#### Constant Voltage Transformers

A group of five new static-magnetic regulators for stabilizing voltage supply to 6.3 volt electron tube filaments is now available from Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill. The transformers are designed for simple mounting as product components, and take the place of conventional, unregulated filament transformers



Transformers for filament operation provide voltage regulated within  $\pm 1$  per cent with line voltage variations as great as  $\pm 15$  per cent. Regulation is automatic and instantaneous, with no moving or renewable parts. No manual adjustments are required. Response time is within 1.5 cps.

Current limiting characteristic of the transformers restrict cold filament current

(Continued on page 166A)

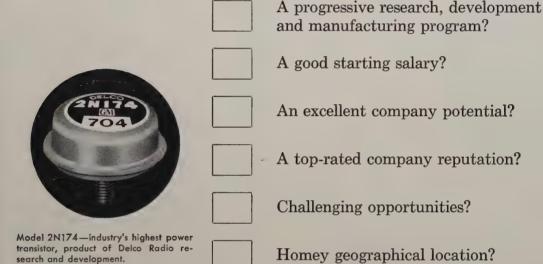
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Box 284, Dept. M-2U, Elmira, N.Y., or phone collect Elmira 9-3611.

Evenings or weekends, phone 2-2139.

## Westinghouse ELECTRONIC TUBE DIVISION BELMIRA, NEW YORK





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(Continued from page 164A)

to an average 175 per cent of the transformer's rated current. Controlled voltage supply extends filament life and improves tube operation. The transformers are available in current ratings of from 5 to 25 amperes, permitting the operation of extensive banks of electron tubes from one filament supply.

For further information on Sola regulators for 6.3 volt filament supply, write

for Bulletin CVF-269.

#### Microwave Power Attenuator

A new power attenuator, designated Model AT-70, has been announced by **Empire Devices Products Corp.**, Amsterdam, N. Y. Designed for Broad-band power attenuation over a range of frequencies from dc to 4000 mc, the new unit may be used for: isolating power sources (up to 50 watts continuous power), from low-power measuring devices, i.e., bolometers; decreasing power output of transmitters (for reduced radiation); or as a dummy transmitter load to permit simultaneous monitoring of transmitter output.

(Continued on page 168A)

#### **PHYSICIST**

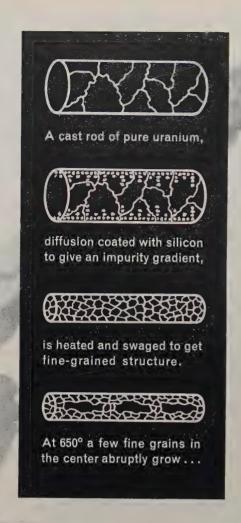
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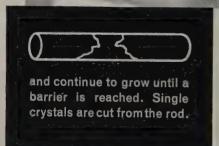
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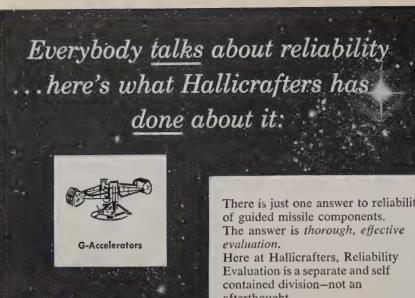


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(Continued from page 166A)



The attenuators are T-networks of concentric line construction and use carbon precision resistors. Series elements are rod resistors, shunt elements are discs. For maximum power dissipation, the AT-70 is oil filled and equipped with cooling fins. Accuracy is within  $\pm \frac{1}{2}$  db and VSWR better than 1.3 to 1 over the entire fre-

AT-70 attenuators have excellent longtime stability and unexcelled over-load characteristics for either CW or pulse operation. Standard attenuation ratios available are 3, 4, 5, 6, 10, 12, 15, or 20 db; rated power is 50 watts continuous, at 125°C; input and output impedance is 50 ohms. (Note: for attenuation values over 20 db, Empire's AT-50 attenuator may be series connected with an AT-70.)

For further information, write for Catalog M-857.

#### Clare to Build New Plant



Expansion of the manufacturing facilities of C. P. Clare & Co., Chicago manufacturer of relays and electronic components, is announced by Carl P. Clare, president. Plans are for immediate construction of a new ultra-modern plant at Fairview, N.C., where the company has been manufacturing in leased quarters for the past two years. The new plant, eleven miles southeast of Asheville, will provide 40,000 square feet and will be completed by June, 1958. The total cost of the facility will be \$1,250,000. Part of the 400 twoshift work force to be employed will be using the building by March.

(Continued on page 170A)

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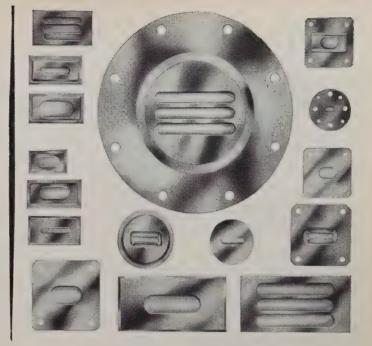


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MA1326	S	2800	2.45-3.15	1.25	1200	48/U	45/30		
MA1352	С	6800	5.85-8.2	1.25	500	50/U	45/30		
MA1347	C	7540	7.0- 8.1	1.10	750	50/U	45/30		
MA1329	Χı	9000	7.5-10.0	1.15	500	51/U	45/20		
MA1329A	ΧL	9000	7.5-10.0	1.15	320	51/U	60/30		
MA1330A MA1344	X	9000 9000	8.4· 9.6 8.5· 9.6	1.15	200 300	52/U	60/30		
MA1344	â	9600	9.3- 9.9	1.08 1.10	20	52/U .2X.9ID	45/30 45/30		
MA1330B	â	9800	8.2-12.4	1.20	200	52/U	60/30		
MA1345	û	9800	8.2-12.4	1.20	300	52/U	45/30		
MA1339	x	9800	9.5-10.1	1.10	20	.2X.9ID	45/30		
MA1333B	Ke	13500	12.8-14.2	1.10	125	91/U	45/30		
MA1340	Ke	13500	12.8-14.2	1.10	125	91/U	45/30		
MA1333A	Ku	15000	12.4-18.0	1.20	125	91/U	45/30		
MA1342	Ku	15000	12.4-18.0	1.20	125	91/U	45/30		
MA1333C	Ku	16000	15.2-16.8	1.10	125	91/U	45/30		
MA1341	Ku	16000	15.2-16.8	1.10	125	91/U	45/30		
MA1348	K	24000	18.0-26.5	1.15	70	53/U	45/30		
MA1334	Ka	34860	33.25-36.5	1.10	40	96/U	45/30		
MA1346	V	70000	65 -75	1.10	12	98/U	45/30		
			SOLDERABL	E TYPE	5				
MA1318	S	2800	2.75-2.85	1.25	170	48/U	60/45		
MA1325	S	2800	2.45-3.15	1.25	1200	48/U	45/30		
MA1306	S	3300	3.25-3.35	1.25	170	48/U	60/45		
MA1351	С	6800	5.85-8.2	1.25	500	50/U	45/30		
MA1321	X	8800	8.5 -9.1	1.25	100	52/U	60/45		
MA1301	X	9000	8.8 -9.2	1.25	20	52/U	60/45		
MA1310	Х	9000	8.8 -9.2	1.25	20	52/U	45/30		
MA1320	X	9000	8.7 -9.3	1.25	100	52/U	60/45		
MA1327	Х	9000	8.4 -9.6	1.25	150	52/U	45/30		
MA1338	X	9000	8.4 -9.6	1.08	200	52/U	60/30		
MA1350	X <sub>I</sub> .	9000	7.5-10.0	1.15	320	51/U	60/30		
MA1302	. <b>X</b> :	9200	8.9 -9.5	1.25	100	52/U	60/45		
MA1312	X	9310	9.0 -9.6	1.25	100	52/U	60/30		
MA1353	Х	9310	9.1 -9.7	1.25	100	52/U	60/45		
MA1319	X	9375	9.1 -9.7	1.25	100	52/U	60/45		
MA1317	X	9600	8.35-11.0	1.25	200	52/U	60/30		
MA1322	×	9600	9.3 -9.9	1.25	100	52/U	60/45		
MA1303	X	9800	9.5-10.2	1.25	150	52/U	45/30		
MA1324	X	9800	9.6-10.0	1.25	20	52/U	45/30		
MA1331	X	9800	9.6-10.2	1.10	150	52/U	45/30		
MA1350A	Χı	9800	8.6-10.6	1.15	320	51/U	60/30		
MA1311	X	9900	8.2-12.4	1.25	200	52/U	60/30		
MA1323	X	9900	9.6-10.2	1.25	100	52/U	60/45		
MA1354	X	10125	9.8-10.4	1.25	100	52/U	60/45		
MA1314	X	10150	9.8-10.55	1.25	150	52/U	45/30		
MA1328		10700	10.0-11.4	1.25	150	52/U	45/30		
MA1336	Ke Ku	13500	13.0-14.0	1.25	40	91/U	45/30		
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1325 -1306		1351	1311 1336 13	37	++++++	1111		
2 3	5 .	6 7 8, 9	IO FREQUENCY (KI	MC/S) 20	30	40 .	60	70 80
1326	DEVELOPMENT	1352 133	308-1345   1333A-13	342 1348	DEVELOPMENT			1346
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Burlington, Mass. BUrlington 7-2711



## American Beauty ELECTRIC SOLDERING IRONS

50-H



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 168A)

#### Mirrored-Scale V-O-M

The Precision Apparatus Co., Inc., 70-31 84 St., Glendale, L.I., N.Y., manufacturer of test equipment, has announced the new Model 120M high sensitivity, multi-range V-O-M featuring a mirrored-scale which makes possible high accuracy readings by eliminating parallex.



Also featured are  $\frac{1}{2}$  per cent tolerance multipliers and 1 per cent accuracy advance design PACE meter which provide  $\pm 1\frac{1}{2}$  per cent accuracy on all dc functions and  $\pm 3$  per cent accuracy on all ac ranges, and a separate function selector position for -dc volts and -dc milliamperes.

Polarity switching is accomplished by changing the Function Selector from +dc to the  $\frac{-\text{dev}}{\text{ma}}$  position to measure -dcv or -ma. The test leads need not be reversed. This is advantageous for repetitive or continuous test monitoring.

The new Model 120M with a sensitivity of 20,000 ohms/volt dc and 5,000 ohms/volt ac, offers 44 ranges. The unit has a 5½ inch meter with 4½ inch window for greater visibility. Range selection is possible with an 18-position, positive-detenting, master range selector equipped with silver-plated contacts.

The Model 120M is net priced at \$52.95, complete with internal ohmmeter batteries, banana-plug test leads and operating manual. Accessories available.

#### New Plant For Ling Electronics

Ling Electronics, Inc., Culver City, Calif., has completed plans for expansion into a second, new plant in Los Angeles, according to an announcement by Cameron G. Pierce, president. The new buildings, located on a 150,000 sq. ft. site will house administrative, engineering and sales as well as additional manufacturing facilities. Architectural plans call for two buildings,

(Continued on page 172A)

## Eremembers the man

## New electronic markets grow where this young man explores!



JACK E. BRIDGES, recipient of the IRE Browder J. Thompson Memorial Prize Award, 1956... for a manuscript by an author under 30 years of age which is the best combination of technical contribution and presentation of the subject.

IRE pays tribute to young Jack E. Bridges for his paper "Detection of Television Signals in Thermal Noise," which appeared in a recent issue of Proceedings of the IRE. His clear, concise theoretical investigation of what goes on in a TV set develops new approaches to picking up weaker signals and getting clearer pictures with less noise. His explorations can expand the TV market by reducing interference from adjacent channels and by improving fringe area reception. Mr. Bridges is still less than 30 years of age but he has proven his is the curiosity of a true radio-electronic engineer. This is the curiosity that builds markets... these are the men IRE always remembers.

The Institute of Radio Engineers is a professional Society of 50,000 radio-electronic engineers devoted to the advancement of their field of specialization. Their official publication, *Proceedings of the IRE*, is concerned solely with these men and their accomplishments. And *Proceedings of the IRE* is the only engineering journal in the radio-electronic industry exclusively edited by and for radio-electronic engineers.

Earth satellites, FM, TV, radar, computers, color TV, transistors, scatter propagation, solid state electronics ... all that is history making in radio-electronics is first presented, then followed step-by-step in its development, on the pages of *Proceedings of the IRE* in authoritative articles by the men behind these advances.

IRE remembers the man! Is it any wonder that the men remember IRE? Best way to get products remembered, if they are sold in the radio-electronics field, is through advertising in the pages of Proceedings of the IRE for ...if you want to sell the radio industry, you've got to tell the radio engineer!



INSTITUTE OF RADIO ENGINEERS

Proceedings of the RE

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THE



## CONTACT MAKING PANEL INSTRUMENTS for the Automatic Inspection or Control between Electrical Minimum and Maximum Limits

Sensitive Research Contact Making Edgewise Panel Instruments provide the means for the electrical sensing of preset values of Voltage, Current, Watts, Micromhos and any

other quantity that can be indicated electrically. They are Reference Standards, modified with adjustable contacts and furnished with electronic relay systems. Their proven Stabil-

ity, Long Life and Traditional Dependability means you

#### 'DON'T HAVE TO WORRY ABOUT A THING.'

- Accuracies to .25%
   7" or 5" hand-drawn mirrored scale
- Automatic or manual reset
   A.C., D.C. or both
- Contacts variable over 90% of the instrument's scale

Rep. in E. Pennsylvania and So. New Jersey - I. E. Robinson Co. Offices - Upper Darby, Pa., Camp Hill, Pa. and Asbury Park, N. J.

Rep. in New England — Yewell Associates, Inc. Offices — Burlington, Mass. and Bridgeport, Conn.

#### SENSITIVE RESEARCH INSTRUMENT CORPORATION

NEW ROCHELLE, N. Y.

ELECTRICAL INSTRUMENTS OF PRECISION SINCE 1927





These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 170A)

double-stored, providing approximately 40,000 sq. ft. Completion for this initial construction is scheduled within 60 days, the announcement stated.



Ling Electronics specializes in the design and manufacture of high-power electronic equipment, including electronically-driven random and sine wave vibration testing systems used in missile, jet, and special industrial testing; radio transmitters, and sonar and ultrasonic generators.

(Continued on page 174A)

#### SPERRY KLYSTRONS

SMX-32 Amplifier-Multiplier 8.0-10.5KMC. Amp.watts at 9000 to 10,500 mc; drive freq. 4500 to 5250 mc. New in original sealed cartons, Guaranteed. Regular price \$925 ea. Our price \$425 ea.

SMC-11 Frequency multiplier 3.75-6.KMC, Freq. multiplier; 7th harmonic output 250 to 600 milliwatts in range 5250-6000mc; 5th or 6th harmonic output 400 to 800 mw in range 3750-5250mc, Drive freq. 715 to 875mc, New in original scaled cartons, Guaranteed. Regular price \$1600 ea. Our price \$495 ea.

#### SCR-584 RADAR



10CM. high power, 250KW. Plan position indicator and slant, range scopes. 360 degree sky search. Full elevation sweep. Will track automatically and feed your computor. Antenna automatically retracts into van for transit, Fully equipped mobile trailer includes heater for personnel, etc. Approximate dimensions 20 x 8 x 15 feet. Condition: as new. Immediate delivery. Installment purchase payments available.

RADIO RESEARCH INSTRUMENT CO. 550 FIFTH AVE. NEW YORK JUDSON 6-4691



#### this is a record of leadership

This Visicorder Oscillograph record\* is a symbol of the leadership that is typical of Honeywell engineering. In laboratories all over the world the Visicorder's instantly-readable direct records are showing the way to new advances in rocketry, control, computing, product design and component test, and in nuclear research.

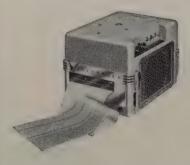
The Model 906 Visicorder is years ahead of the trend. It is the first recording oscillograph that combines the convenience of direct recording with the high frequencies and sensitivities of photographic-type instruments. The Visicorder alone among oscillographs makes it possible for you to monitor high-speed variables as they go on the record.

To record directly the high frequency variables you need to study, use the Visicorder Oscillograph. Call your nearest Minneapolis-Honeywell Industrial Sales Office for demonstation.

\*reproduced half size

Minneapolis-Honeywell Regulator Co., Heiland Division, 5200 East Evans Avenue, Denver 22, Colorado.

Reference Data: Write for Visicorder Bulletin



Honeywell

Heiland Division



#### FM-AM STANDARD SIGNAL GENERATOR

#### Type MS27

FREQUENCY:

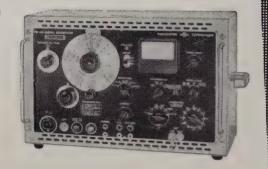
0.3-240 Mc/s in 5 ranges

Normal: ± 5, ± 25, and ± 75 kc/s ranges High: ± 75, ± 150, ± 300, and ± 600 kc/s depending on frequency range

AM:

DISTORTION:

<2% at ± kc/s FM <5% at 50% AM





O.TPUT: 0.1 µV to 0.1V across 50 or 75 ohms: in 1 dB steps • Crystal calibration of dial • Direct reading ± 50 kc/s Incremental Frequency dial • 50 and 75 ohms source impedances • Rugged militarized construction.

#### RADIOMETER

72 Emdrupvej, Copenhagen NV-2, Denmark

Represented in Canada by

BACH-SIMPSON · London/Ontario

Represented in the United States by

WELWYN INT. INC. • 3355 Edgecliff Terrace, Cleveland 11, Ohio



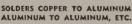


CAP TOP UTILITY BOX

BOX LMB CHASSIS

ENGINEERED PRECISION LINE "SAL-MET"

NON-CORROSIVE SHIELDED CHASSIS





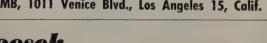


"SAL-MET" NON-CORROSIVE FLUX—solders copper to aliminum, aluminum to aluminum; in fact, any metal to any metal is possible when using "SALMET" No special preparation on material to be soldered. Use conventional solder, applied with quick heating, regular soldering iron, torch or port. Used by aircraft, povernment agencies and leading industrials. Stocked nationally by electronic distributors. Send for free information and catalog. Send for both LMB Catalog and SAL-MET Catalog to:

TWO QUALITY PRODUCTS USED BY ENGINEERS

LMB the engineered precision box chassis, engineered and built by engineers for engineers. It different types, 160 different shapes and sizes for the laboratory, manufacturer, engineer, industrial, experimentor, builder and general application where metal boxes are required and used. Stocked nationally by electronic and geo-physical distributors. Send for free catalog.

LMB, 1011 Venice Blvd., Los Angeles 15, Calif.





toroidal coil winding machines . . .





feature one-piece shuttle, speed and easy operation . . . . . . the world's most capable winders.

BOESCH MANUFACTURING CO., INC. - DANBURY, CONN.



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(Continued from page 172A)

#### Ferrite Isolators

Raytheon Manufacturing Co., Special Microwave Device Group, Seyon Bldg., Waltham 54, Mass., announces high-power  $K_u$ -band ferrite isolators are now available in standard models.



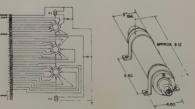
Model  $IK_uH1$  covers a frequency range of 16.0 to 17.0 kmc; it provides a minimum of 20 db isolation and a 0.5 db maximum insertion loss over the full band. The unit weighs less than  $2\frac{1}{2}$  lbs and is  $3\frac{1}{4}$ inches long.

Model IK, H3 is a miniaturized unit which weighs less than  $1\frac{1}{2}$  lbs and is less than 2 inches long; it nevertheless provides a minimum isolation of 14 db and a maximum insertion loss of 0.3 db over the 16.0 to 17.0 kmc band.

Both of these units have a power handling capability of 135 watts average, 135 kw peak.

Modified standard units are available on special order to meet particular performance or packaging requirements.

#### Remote Switching Mechanism



A unique 10 pole double throw versatile hermetically sealed self-stepping remote switching mechanism capable of electrically opening or closing and manually opening with an extremely low contact resistance of 0.1 ohm maximum at 300 milliamperes at approximately 6 vdc constant throughout life has been developed by John Oster Mfg. Co., Avionic Div., 1 Main St., Racine, Wis. Type SWM-9610-04 has a minimum life of 10,000 positive electrical cycles and 100 positive manual cycles. Visual indication instantly shows open or closed switch position. Con

(Continued on page 176A)

## I want a "Whatcha-ma-call it?" It's a "thinga-ma-jig that...."

How often have you struggled to remember the name of a component or electronic item. . . . Just could not think quickly what it is called?

## YOU CAN FIND IT IN THE IRE DIRECTORY! because.

- (1) The IRE Directory classifies products by purpose and use
  - (2) Its listings are fundamental—the way an engineer thinks
    - (3) "Terminology" is cross indexed in the pink pages—condensed, simple, not mixed in with firm names.
      - (4) Ads face listings thus helping to identify products by actual pictures.
        - (5) Product code numbers reduce complex and duplicate listings, saving you "searching" time and effort.

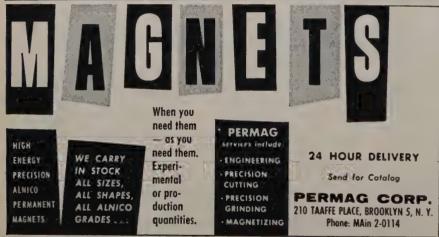
Your IRE Directory (member copy) will reach you by November 1
Study it . . . save it . . . work it.



#### THE INSTITUTE OF RADIO ENGINEERS

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### CAPITOL RADIO ENGINEERING INSTITUTE

Advanced Home Study and Residence Courses in Practical Radio-Electronics and Television Engineering Technology



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(Continued from page 174A)

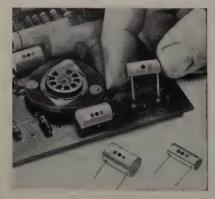
tacts are capable of carrying 15 amperes with a make or break capacity of 5 amperes 125 volts. Solenoid current is 4.8 amperes ±0.5 amp at 24 vdc instantaneous. Solenoid circuits may be energized indefinitely. The self-stepping unit contains arc suppressors for contact protection of all stepping circuits. The hermetically sealed case contains nitrogen under a pressure of approximately one atmosphere. Meets Mil-E-5272 but can be extended to +250°F for special applications. The device is designed for switching precision circuitry.

#### Servo Amplifier Brochure

M. Ten Bosch, Inc., Pleasantville, N. Y., has published a new "Transistor Servo Amplifier" brochure, four pages which covers the performance characteristics of production models of the 60 and 400 cps TRAMPS. Miniaturized units capable of providing up to 9 watts controlled power at a weight factor of less than 1 ounce per watt are described in detail. An engineering application questionnaire is included to assist in the selection of the TRAMP and control system companions which were designed to military specifications.

#### Standardized Radial Lead Coils

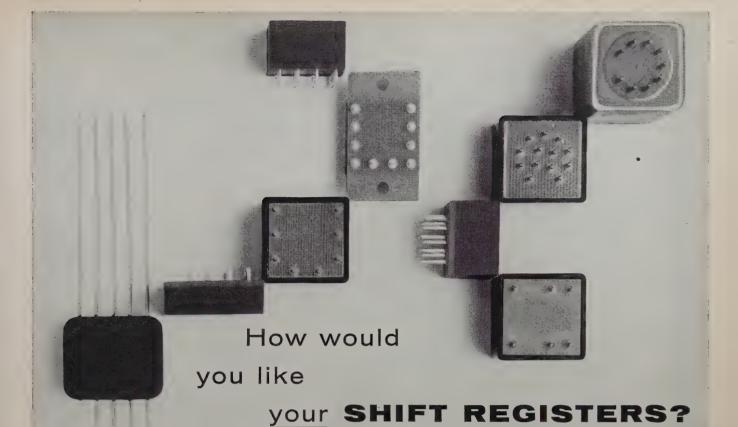
Delevan Electronics, East Aurora, N.Y. (Buffalo suburb) has just introduced a complete series of 42 radial lead coils. The inductance values of these coils range from 0.47 to 10,000 microhenries. All other values are exactingly defined for easy engineering evaluation.



Each coil is hermetically encapsulated in molded alkyd plastic making it possible for all coils to easily conform to MIL-C-15305A specifications.

There is a "Flat" base molded in the body of each coil at the lead exit to permit secure placement of coils or printed circuit

(Continued on page 178A)



Whatever your requirements relating to buffer storage, pulse distribution or other pulse, digital and

logic functions, we would like to talk to you about them. Epsco designs a wide variety of transistorized, transistor-driven and tube-driven shift registers and magnetic logic elements, featuring high reliability, low-power consumption and compactness . . . and manufactures them in volume right to the letter of each individual specification.

Custom engineering-production of electronic components (shift registers, magnetic logic elements, delay lines, special pulse transformers, etc.) is our specialty. You can count on the cooperation of Epsco's engineering staff and field representatives for effective, economical fulfillment of your performance requirements and for conscientious service right down the line. Your inquiry will receive prompt action. Write for Shift Register technical bulletin.

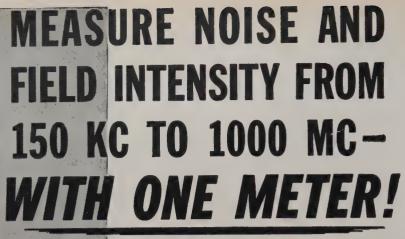
Epsco, Incorporated, Dept. P-107, 108 Cummington St., Boston 15, Mass.

START-TO-FINISH cooperation
... an Epsco guarantee

## Epsco

#### SALIENT FEATURES OF EPSCO SHIFT REGISTERS

- Standard packaging—9-pin miniature base, dip-solder terminals for printed circuits, and solder-lug panel with mounting ears; standard epoxy and hermetically sealed cases, or custom packaging to your specifications.
- Minimum size—below ¼ cu. in. per binary digit.
- Surpass applicable MIL specification.
- Extremely low power consumption—less than 0.25 watt peak power for 3kc rate; 0.6 watt peak power for 100 kc rate.
- Wide operating tolerances: dependable field performance.



Quickly · Accurately · Reliably



Model NF-105 (Commercial Equivalent of AN/URM-7)

Empire Devices Noise and Field Intensity Meter Model NF-105 permits measurements of RF interference and field intensity over the entire frequency range from 150 kilocycles to 1000 megacycles. It is merely necessary to select one of four individual plug-in tuning units, depending on the frequency range desired. Tuning units are readily interchangeable...can be used with all Empire Devices Noise and Field Intensity Meters Model NF-105 now in the field.

Each of the four separate tuning units employs at least one RF amplifier stage with tuned input. Calibration for noise measurements is easily accomplished by means of the built-in impulse noise calibrator. With this instrument costly repetition of components common to all frequency ranges is eliminated because only the tuners need be changed. The same components...indicating circuits, calibrators, RF attenuators, detectors and audio amplifier... are used at all times.

Noise and Field Intensity Meter Model NF-105 is accurate and versatile, it may be used for measuring field intensity, RF interference, or as an ultra-sensitive VTVM. A complete line of accessories is available.

For complete performance data, send for Catalog No. N-356

#### EMPIRE DEVICES

PRODUCTS CORPORATION

AMSTERDAM, NEW YORK

Telephone: Victor 2-8400

manufacturers of

FIELD INTENSITY METERS - DISTORTION ANALYZERS - IMPULSE GENERATORS - COAXIAL ATTENUATORS - CRYSTAL MIXERS



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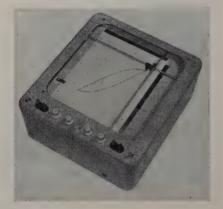
(Continued from page 176A)

boards. The radial leads are suitable for either automation equipment or hand insertion. Leads are spaced at 0.100 inch increments.

As part of a series of 150 coils these radial leads coils are now a standardized, stock item for Delevan. Delivery is made "off-the-shelf."

The 42 radial lead coils range in size from 0.235 in diameter and 0.625 in length to 0.500 in diameter and 0.825 in length with 5 different mold sizes available.

#### X-Y Plotter



The ER-90 X-Y plotter, completely redesigned and repackaged is now available from Mandrel Industrial Instruments, division of Mandrel Industries, Inc., 5134 Glenmont Dr., Houston, Texas. With an input sensitivity as high as 1 millivolt per inch, the ER-90 X-Y plotter features a flat bed construction for full chart visibility and a slip-on pen plotting on standard 8½×11 inch paper. Reliable operation is insured by conventional chopper-stabilized amplifiers and standard 3 turn rebalance potentiometers in the null-seeking servo system plus a simplified cord drive system. The two axes are electrically independent. Priced at \$520, this recorder has a limit of errors better than 0.75 per cent, and a repeatibility better than 0.5 per cent. Full details may be had by writing to the firm.

#### **Tubeless DC Supply**

Opad Electric Co., 69 Murray St., New York 7, N.Y., announces the Model TM25, a tubeless laboratory type regulated dc power supply with a continuous duty rating of 0–150 volts dc at 2 amperes. Voltage regulation is held to  $\pm 1$  per cent and ripple is less than 0.03 per cent of the average dc at maximum output.

Extremely compact, the unit occupies  $8\frac{3}{4}$  inches of panel height. Depth behind the panel is nine inches.

(Continued on page 180A)

T2/NF-105:



SILICON RECTIFIERS are finding increasing use at elevated temperatures in aircraft and missile applications by providing more power per pound.

## Now...design improvements made possible with components of Du Pont Hyperpure Silicon

Today silicon rectifiers make possible a vast improvement in jet-age aircraft generators—the use of engine oil as a coolant instead of less-efficient ram air. Silicon rectifiers take the place of oilsensitive brushes, commutator and slip rings . . . are completely unaffected by 150°C. engine oil. Result: a brushless generator of less weight and size than ordinary generators.

Silicon devices can similarly help you miniaturize—improve design and performance. Silicon rectifiers have excellent stability . . . can operate continuously at -65 to 200°C. They're up to 99% efficient—reverse leakages are only a fraction of those of other semiconductors. Both transistors and rectifiers of silicon can pack *more* capacity into *less* of your equipment space.

#### Note to device manufacturers:

You can produce high-quality silicon transistors and rectifiers with Du Pont Hyperpure Silicon now available in three grades for maximum efficiency and ease of use...purity range of 3 to 11 atoms of boron per billion...available in 3 forms, needles, densified, cut-rod. Technical information is available on crystal growing from Du Pont... pioneer producer of semiconductor-grade silicon.



#### NEW BOOKLET ON DUPONT HYPERPURE SILICON

You'll find our new, illustrated booklet about Hyperpure Silicon helpful and interesting—it describes the manufacture, properties and uses of Du Pont Hyperpure Silicon. Just drop us a card for your copy. E. I. du Pont de Nemours & Co. (Inc.), Pigments Department, Silicon Development Group, Wilmington 98, Delaware.

#### PIGMENTS DEPARTMENT



BETTER THINGS FOR BETTER LIVING
...THROUGH CHEMISTRY

PROCEEDINGS OF THE IRE October, 1957



MEASUREMENTS, INC.



### CAPACITANGE BRIDGE

A precision laboratory bridge designed to measure a wide range of capacitance at audio frequencies. Extreme simplicity of operation with direct-reading dials and multipliers, plus dual range null indicator. Excellent shielding; no zero capacitance correction needed with suitable test leads. Unique carrying handle converts to adjustable bench stand.







These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 178A)



Controls include a power switch, pilot light, indicating type line and load fuse, a 4½ inch 2 per cent accurate dc voltmeter and ammeter and a pair of 5-way insulated binding posts. An additional pair of output terminals are provided at the rear of the chassis.

The equipment is also available in a cabinet for bench use. The bench unit is designated Model TM25B.

#### Transistorized Power Converters



Southwestern Industrial Electronics Co., P.O. Box 13058, 2831 Post Oak Rd., Houston, Tex., now offers a line of Transistorized Power Converters which will find wide usage whenever it is desired to obtain high voltage dc from a low voltage dc supply. The TPC-2 shown here is designed for 12 volts input and 150 volts, 400 ma or 300 volts, 200 ma output. It draws 6.85 amperes full load and 1.12 amperes no load. This small, compact unit has an efficiency of better than 75 per cent and is expected to be invaluable in replacing dynamotors and vibrator type power supplies. It will operate at ambient temperatures up to 150° F. under continuous full load conditions.

#### X-Y Recorder

A new Electronic Dynamaster X-Y Recorder has just been announced by The

(Continued on page 182A)

## differential DATA AMPLIFIER

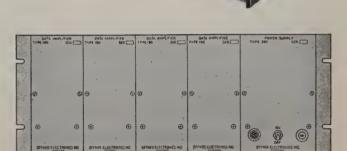
d-c Amplifier with zero drift and 1/100th percent gain stability

For amplification of thermocouple, strain gage, and similar low level signals the Type 190 Data Amplifier provides a combination of features available in no other amplifier:

- Infinite rejection of common-mode d-c signals
- One microvolt input resolution
- ☆ Gain stability of 0.01%
- Rapid step input response
- ☆ Linearity of 0.05%

The true differential response of the Type 190 provides increased accuracy and simplified installation for data reduction, control, and similar applications. With infinite rejection of common d-c signals, and a rejection ratio at 60 cps of the order of a half million, errors due to ground currents are completely eliminated, and pickup problems greatly diminished.

The Type 190 is designed for fixed-gain operation from low impedance sources, into high impedance load. Gain may be set at values ranging from 160 to 1200. Amplifier characteristics are unchanged at ambients from  $-67^{\circ}\text{F}$  to  $+170^{\circ}\text{F}$ .



Four Type 190 Amplifiers mounted in BM190 modular rack unit with Type 390 power supply.

Price of Type 190 Amplifier\$325
Type 390 Power Supply, for up to
four Type 190 Amplifiers \$250
Type BM190 Rack Unit for four Type
190 Amplifiers and Type 390 Power
Supply\$140

Ask for bulletin No. 572 giving full technical information



#### OFFNER DYNOGRAPH Direct-Writing Oscillograph

Zero-drift d-c recorder with microvolt sensitivity. One amplifier type covers all requirements.

Models for one to 19 channels.

Rectilinear or curvilinear recording.

Ask for bulletin No. L-861

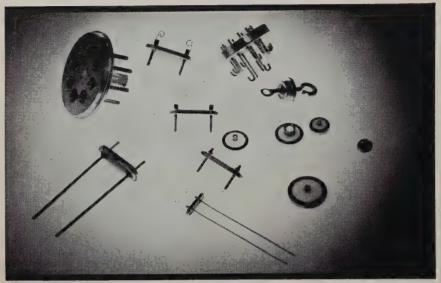


#### OFFNER ELECTRONICS INC.

5328 N. Kedzie Avenue, Chicago 25, U.S.A.

## PHILLIPS HERMETIC SEALS

The Man from Phillips is the man to see for glass-to-metal seals — any type, any size, any quantity, standard or custom-engineered. Exceptionally fast delivery. Write for catalog.



Phillips Control Corporation, Joliet, Illinois — AN ALLIED PAPER CORPORATION SUBSIDIARY — SALES OFFICES: NEW YORK - PHILADELPHIA - BOSTON - SAN FRANCISCO - DENVER - SANTA MONICA - WASHINGTON - WINSTON SALEM - CLEVELAND - DALLAS - SEATTLE - KANSAS CITY - ST. LOUIS - DETROIT

### Simplifying HF Power Measurement

## Model 67 TERMALINE DIRECT-READING R-F WATTMETER

30 mc to 500 mc (to 1000 mc if specified)

50 ohms

Triple Range 0-25 watts

0-100 "

0-500 '

Type N Input Connector (Adaptor for PL-259 supplied)

Model 67 is a larger type Wattmeter than the well-known AN-ME-11/U (our Model 611) R-F Wattmeter. Specifically designed for fixed station transmitters to 500 watts output, it may be used nicely on low range for mobile gear. Provided with an aluminum cased, shockmounted meter, Model 67 is as simple to use as a DC voltmeter. Now in general use throughout the industry, TERMALINE Wattmeters may be depended upon for fast, accurate and repeatable power readings



NON-RADIATING

... Accuracy - 5%

RUGGED CONSTRUCTION

... Size - 17" x 9" x 6"
Wght. - 30 pounds



## ELECTRONIC CORP. 1800 EAST 38TH ST., CLEVELAND 14, OHIO

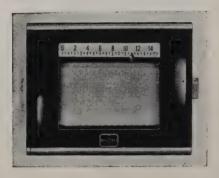
VAN GROOS COMPANY Sherman Oaks, Cal.



These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 180A)

Bristol Co., Waterbury 20, Conn. The new strip-chart recorder will automatically plot a continuous curve showing the relationship of one measured variable to another.



Some typical uses for the instrument include plotting temperature versus pressure in the process industries, position of intake parts versus gas flow in wind tunnel research, location on web versus thickness in paper making, and speed versus torque in motor operation. Most other variables can also be handled.

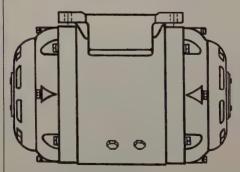
The Dynamaster records on a 12-inch strip chart, and is available in pen speeds of up to 0.4 seconds for full scale traverse to follow the most rapidly changing variables. Standard accuracy is 0.25 per cent

Additional information is available from the company.

#### 2000 Watt Converter

What is to be the largest dc to ac converter in the quarter-century history of Carter Motor is now in process of development. Actual production is expected to begin in October.

Information can be had by addressing Ray Simon, Chief Engineer, Carter Motor Co., 2711A W. George St., Chicago 18, Ill.



The drawing above is copied from original engineering diagrams, and indicates the heavy duty construction of the converter. Overall size is 11×19×12 inches high. Drip proof ventilation and marine specifications will be employed,

(Continued on page 184A)

## First Power Tetrode!



#### Faithfully reproduces input signals—frequency response improved 50%!

Now, FOR the first time, you can get a transistor that gives low audio distortion, high efficiency and high power output—with high impedance drive and without feed-back.

This performance is now provided by the new Honeywell H200E Tetrode Power Transistor. The Power Tetrode has two separate base connections permitting control of the device characteristics.

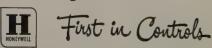
In addition to improved linearity, Frequency Response is increased 50% over triode transistors!

Also, Thermal Stabilization of the Power Tetrode is achieved more easily than with triode transistors because of the second base connection. This stabilization can be achieved even with high impedance drive, allowing high temperature operation of direct coupled circuits using Power Transistors.

The H200E is a germanium PNP alloyed junction power transistor designed to operate on 28-volt systems with currents up to 10 amperes. Its thermal resistance is less than 1°C/watt.

The Power Tetrode is available in sample quantities. Get complete information by writing Honeywell, Dept. PI-10-262, Minneapolis 8, Minn. Regional representatives may be reached in Union, N. J. (MUrdock 8-9000), Boston (ALgonquin 4-8730), Chicago (IRving 8-9266), and Los Angeles (RAymond 3-6611 or PArkview 8-7311).

### Honeywell





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(Continued from page 182A)

making the converter serviceable under the most exacting conditions.

Input voltage models will be available for 32, 48, 64, 115 and 230 volts dc with ac outputs of 115 or 230 volts, 50 or 60 cps, single or 3 phase. Output capacities of 1500 or 1250 watts will also be offered, in addition to the 2000 watt model.

Most significant engineering feature is the use of four-pole design to reduce armature operating speed to 1800 rpm with consequent longer life and quiet operation. Amortisseur armature windings are employed for ac output stability and improved dc commutation is obtained by use of interpoles.

#### Dual-Channel Telemetering And Control Terminals

Designed by Moore Associates, 2628 Spring St., Redwood City, Calif., for telephone lines or cables with up to 20 db attenuation between associated transmitter and receiver, these self-contained units have application in remote industrial control and recording. When keyed by switches for control applications or pulsewidth signaling transducers for metering, the Model 55 Transmitter (right), provides two independent signaling tones in the frequency range 2.8 to 100 kc. The frequency is precisely controlled by interchangeable plug-in networks for each channel. The receiver (left) provides two independent regulated outputs up to 20 and 50 ma for recording transmitted data or, by means of plug-in hermetically sealed DPDT relays, up to 20 amperes at 250 volts for on-off apparatus control over each channel. The plug-in relays can control up to 1-horsepower motors without the need for auxiliary contactors.



One feature is the narrow bandwidth required for each channel, 0.2 per cent, and the close spacing between channels that can be used. The stable plug-in networks permit channel spacing closer than 1.5 per cent in frequency. This makes available more than 200 separate control channels over one telephone line using frequencies between 3 and 100 kc without interferring with the use of the line for normal voice communication.

(Continued on page 186A)

#### Monitor radiated signal frequencies 100 times faster!

with accuracy of  $\pm$  1 cps...over range of 0.54-30.5 megacycles



Beckman/Berkeley Model 7700 Microsensitive Frequency Measuring System

Featuring

**Exclusive direct digital readout** —7-place numerical display for speed, accuracy and convenience.

**Broad utility**—measures AM, ICW, frequency shift keyed and multiplexed signals.

**Extreme sensitivity**—detects and measures signals of 1 microvolt strength.

Advanced engineering design — exceeds FCC specifications, is suitable for compliance with Part 15, FCC Rules and Regulations.

Wide range and bandwidth selectivity— 30 1-mc frequency bands; bandwidth of 100 cps-6 kc for interference rejection.

Price: \$3500.00 F. O. B. factory

#### DESIGN AND PERFORMANCE SUPERIORITY

Comprising a unique combination of a quality communications receiver and a high-speed electronic counter, Beckman/Berkeley Model 7700 provides 100,000 times the customary counter sensitivity, and 100 times the frequency measurement speed of other equipment. Its extreme sensitivity and accuracy permit quick, precise measurement of virtually all types of radiated signals in the 0.54 to 30.5 megacycle range, with maximum error of 1 in 10<sup>7</sup>.

Simple and easy to use, the Model 7700 makes possible the measurement and monitoring of broadcast or other frequencies by non-technical personnel with a minimum of training. The system consists of three basic units: a broad range communications receiver, a translator with oscilloscope comparator, and a timegated electronic counter. An audio system is incorporated for aural monitoring where desired.

Complete technical information on the Beckman/Berkeley Model 7700 Microsensitive Frequency Measuring System is available on request. Write to Dept. N10.

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14



"Is seat of pants Amerikan spacemen is flying by. Is not knowing of Reeves-Hoffman's . . .

### NEW HIGH PRECISION CRYSTAL FOR FREQUENCY MEASUREMENT

WRITE FOR BULLETIN RH-5MC.

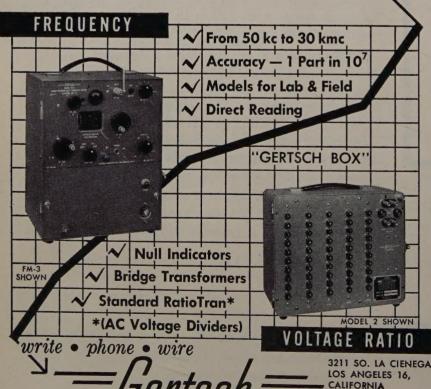


Designed for use as frequency standards, Reeves-Hoffman's new 5mc, high precision crystals offer exceptionally long term frequency stability, ±.0001%, with aging of less than one part per 10<sup>8</sup> a week! These units are available in hermetically sealed glass T5 1/2 enclosures with pigtail leads or 9-pin Bakelite bases. They are manufactured to meet the most exacting military and commercial standards for frequency measurement.

DIVISION OF DYNAMICS CORPORATION OF AMERICA

CARLISLE, PENNSYLVANIA

for precise measurements





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(Continued from page 184A)

#### Converter Catalog

An entire new line of dc to ac converters is presented in Converter Catalog #557, recently issued by Carter Motor Co., 2711A W. George St., Chicago, Ill., manufacturers of rotary electric power supplies.

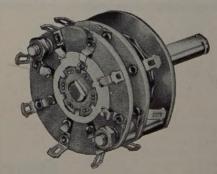


It presents illustrated listings of the new Mark II Super Converters introduced by Carter this year, including special models engineered for railroad, marine and industrial service. This new line has been entirely re-designed for better appearance, longer life and improved performance. A new "Geneverter" is also listed, providing a reliable low cost dc to ac converter in minimum space, for use in control circuits and industrial applications requiring output capacities of 20, 40, or 60 watts.

Copies may be secured from Carter representatives in principal cities, or by addressing the factory direct.

#### Miniature Rotary Switch

In keeping with the trend for miniaturization in low-current switching, Oak Mfg. Co., 1260 Clybourn Ave., Chicago 10, Ill., has developed a tiny rotary switch that will fit in a  $1\frac{1}{8}$  inch circle, requiring less than one square inch of panel area.



The new switch is designated as "Series A" and can be supplied in 8, 10, and 12-position wafers, with the latter providing up to 18 insulated contacts.

Standard shaft diameter for the new

(Continued on page 188A)

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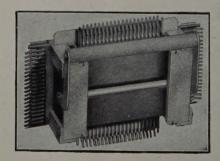
(Continued from page 186A)

"Series A" is  $\frac{1}{4}$ , but 5/32 and  $\frac{1}{8}$  inch shafts are also available. Clips are a miniature version of the standard Oak double-wiping design. They are formed from either solid spring-silver alloy or silver-plated spring brass. Solid rivets fasten clips to the switch sections. Silicone fiber glass, meeting Specification MIL-997 Type GSC, is used for the switch stator. The rotor is punched from KEL-F.

Complete information and technical data are available through local representatives or from the Oak Mfg. Co.

#### Punched Card Reader

This punched Card Reader developed for Cinch Mfg. Corp., 1026 S. Homan Ave., Chicago 24, Ill., is a simplified circuit switching device, which provides a substitute for patch cord panel systems used in the changing of circuit connections at random intervals. It features a molded block with 400 floating contacts passing from one face to the other. This block is sandwiched between two printed wire boards having strip conductors in various grill-like formations. The contacts make connections between groups of conductors on one of these printed wire boards to other groups on the other, except where a card interposes an insulation. Perforations in the card permit connections to be made where desired, and to be changed by substituting a new card.



Ordinary 3×5 inch cards are used, containing the 400 hole positions, in a 20 by 20 array. Facilities for perforating the cards as required are to be made available. The contact blocks can be mounted in multiples for complicated switching problems, augmented by larger printed wire boards.

In use, a card is inserted in the slot at the top and the lever closed. Safety features include means for insuring that the card is inserted in the correct position, and that closure is not made while a card is missing. Provision is also made so that the circuits are disconnected before the contacts are opened. This insures that all circuits are "dead" when closures are made or opened. Due to the wide variety of configurations possible with the printed wiring boards, this Reader will find applications in the most complicated circuit switching.